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INTERNATIONAL TELECOMMUNICATION CONFERENCES.

BY REAR ADMIRAL STANFORD C. HOOPER, U. S. NAVY, MEMBER.*

Rapid expansion and improvement in all forms of communications have made it necessary for the nations of the world to hold many international communication conferences, especially since the World War. These conferences serve to arrange neatly the intricate web of communication services, the nervous system of the modern world. The United States has had a vital interest in all of them, and has usually been represented. The Navy, because of its superior experience with the subject and to protect its own interests, has often assisted both in the preparations for the

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collaborations and as a part of the American delegation. The author has been intimately associated with telecommunications since the early days of wireless communication. He has guided the development of communications in the Navy. The Society is fortunate in publishing this article written by him since his return from the recent conference in Cairo, Egypt.

Telecommunications embraces telephony, telegraphy, and radio. There are two basic treaties governing these subjects, one the International Telegraph Convention and Regulations, and the other the International Radio Convention and Regulations. These treaties are revised every four or five years. Both revisions are made at what is called the "Telecommunications Conference," the most recent one having been held in Cairo, Egypt, February 1 to April 8, 1938. Over three hundred delegates, representing roughly seventy nations, participated in the discussions. In addition to this number of delegates were nearly two hundred representatives of communication companies, press services, broadcast interests, air services, amateurs, and other interests. Including staffs, ladies, and children of the representatives, approximately one thousand persons were in the conference register. Our own government delegation included four delegates and nine expert advisors, together with a staff of 22 clerks, translators, and secretaries, also non-government representatives who were there as observers, and to assist the delegation in any way possible, especially with data concerning their respective interests.

French and English are the languages of these conferences, and translations are made of all addresses from one language to the other so that all delegates can keep up on what is being said. Also, the minutes of all meetings are distributed the following morning in mimeographed form in both languages. The final treaty wording is in French.

The treaties embrace rules for operation, classification of traffic, procedure, rates, division of radio channels to services, priority rights, standards of service and qualifications for operators, SOS

and other safety signal devices, secrecy of messages, avoidance of interferences, classification of radio missions, procedure for reporting irregularities and violations of the rules, call signals, routing instructions, time zones, hours and services, and, in fact, all conceivable regulations necessary to guide the communications authorities of the nations of the world in handling international rapid communication traffic.

The treaties also include rules covering the procedure for assembling the conferences, including details as to organization, committees, and rules governing debate, signing, and ratification.

Brief History of Radio Treaties.

Theodore Roosevelt is credited with instituting many unusual activities in foreign relations. Probably none had more far-reaching consequences than his support of efforts to bring about the regulation of radio. Many persons concerned with radio today have probably forgotten the incident which aroused Roosevelt's interest in radio. To those concerned with the history of radio, however, it illustrates the difficulties experienced whenever efforts were made to restrict and limit the development of radio communication to the use of a particular type of apparatus by patent monopolies or restrictive agreements.

In 1902, Prince Henry of Prussia visited the United States, and as he neared the Isle of Wight on his return voyage on the German Steamship *Deutschland,* he wished to send a radiogram to President Roosevelt thanking him for the many courtesies and honors he had received during the visit. The radio equipment of the ship was not powerful enough to communicate with radio stations in the United States and so an English station was requested to receive the message and retransmit it to the United States by cable at the expense of the German ship. The shore station in England, however, was equipped with Marconi apparatus while the German ship was equipped with Telefunken. Since the two telegraph corporations were rivals, the English station declined to accept the message. Upon his return to Berlin, Prince Henry reported the incident to his brother, Emperor William.

In consequence, Emperor William with Roosevelt's cooperation, arranged to have an international radio conference held at Berlin in 1903. The chief subject discussed at the conference was whether the station of any company should be allowed to decline messages from ships at sea. A draft convention was prepared, but failed to become effective, due principally to the opposition of the Marconi company.

A second and more successful conference was held at Berlin in 1906 for here a convention was signed and ratified making it compulsory for all coast stations to receive and forward the radiograms from vessels at sea irrespective of their system of communications. The convention was promptly submitted to the Senate, but the United States did not become a signatory until the third international radio convention which was held in London in 1912.

At this time, there was little application of radio except as a means of communication with vessels at sea. Then and often now, this is a highly-important purpose, but it has ceased to be the only one. The 1912 convention directed itself entirely to means of radio communication and it wisely made no effort to regulate in the unknown future. This conference found it necessary to deal with only a few frequencies, and having allocated the 500, 600 and 1600 meter wave lengths as the calling and normal channels for ship communications, its task in this regard was completed.

In a short period of time the advancement of the art rendered this convention inadequate. The original relation of radio to ship communication had enormously expanded and the direction finder had come into general use. Under the increased application of radio at sea the loss of life and property had been enormously decreased. Today in national defense, navigation, commerce, radio telephone broadcast, in apprehending crime, and in many other ways, it has come to play an important part in the lives of the people.

It is obvious that the number of frequency channels through the ether is limited and that they must not only be organized, but conserved to the most vital uses. As a result of all these limitations, these uses for the radio spectrum undreamed of in 1912, must seriously threaten our communications through the chaos of un-

coordinated traffic. Every new service of radio demands its place in the ether, and right-of-way on channels for its service. Multiplication of uses, the requirements of the old, the demands of the new, necessarily increase the probability of interference and of confusion. The provision of channels for each becomes increasingly important, and at the same time progressively difficult. The contrast of the problems of 1912 with those of today are quite apparent. In those days the primary difficulty was the establishment of communication. Today it is the congestion and interference of actual communications conducted.

In 1927, there was made the first really significant attempt to solve the international problems raised in the field of radio communication. At the international radio telegraph convention held in Washington, the frequency spectrum was broadly considered. No attempt was made to allocate the channels to the various nations of the world. The resulting treaty was confined merely to an obligation to avoid interference and divide up the entire radio frequency spectrum, 0-23000 kcs., into bands to be devoted to the various kinds of services.

Research and experience in the years immediately preceding the Washington Convention had brought about the realization that perhaps the most valuable source of communication channels was being neglected. The imaginary deadline between high and low frequencies had been obliterated. All frequencies are now considered available for some purpose and the question is as to their most efficient and effective utilization. The major tasks of the Washington Convention in 1927 were the allocation of the remaining frequency channels among the different international services. Except for the provisions of the London Convention's application to marine communications and for some regional understandings of limited territorial extent, all of these new services which make up by far the major block of radio transmissions today were unregulated in their international aspects. The general results of the Washington Convention were regulating the use of bands of frequency channels for specific purposes. The radio frequency spectrum has been divided into six major bands as follows:

(*a*) Low-frequency: 10 to 100 kcs.
(*b*) Medium-frequency: 100 to 550 kcs.
(*c*) Broadcast: 550 to 1500 kcs.
(*d*) Medium high-frequency: 1500 to 6000 kcs.
(*e*) High-frequency: 6000 to 30,000 kcs.
(*f*) Very high-frequency: above 30,000 kcs.

The channels from 10-100 kcs. were set apart for long-distance oceanic service. The channels from 100-550 kcs. were set apart primarily for ship-shore and aircraft service. The channels from 550-1500 kcs. were allocated to broadcasting. The very great number from 1500 to 6000 kcs. were divided into nearly a thousand channels and apportioned to the several varieties of service, such as, point-to-point, maritime, aviation, special broadcasting, experimental visual, emergency, police and amateurs. The amateur was recognized as an important element in radio communication and had conferred upon him rights by international treaty with definite channels of communications. Above 6000 kcs., up to 30,000 kcs., lie the very important channels which are most useful for long distance communications, and, therefore, have a most important aspect as regards international relations. There are nearly 1400 of these channels which have been assigned to various services engaged in long distance communications, and it is in this portion of the radio frequency spectrum that some of the most difficult problems of international interference arise.

The Convention established regulations for each of the different bands assigned to specific purposes. In the mobile band, mostly used for ship communications, it more clearly defined and strengthened the requirements with a view to greater safety of life and property at sea. These regulations set forth detailed rules of practice for communications from ship to shore, and facilitated the establishment of coastal communications. They gave full place to that invention, the radio direction finder, and further gave distress communications priority over the world's other communications.

The broadcasting band was clarified and defined for the whole world in such fashion that there would be less conflict and interference—a direct contribution to every owner of a receiving set.

Point-to-point radiotelegraph service was assigned in such fashion as to permit future expansion throughout the world.

The range of higher frequencies, above 30,000 kcs., is a field still open to great developments in the art. This region is so divided as to give stimulation to the many applications which are now tentatively under investigation, such as short distance point-to-point telephone, television, and synchronized broadcasting, remote control circuits and similar applications.

In the broader sense, the Washington Convention was an outstanding effort toward the reduction of interference. Freedom was left for national determination of all questions which do not involve international interference. The Convention had before it the necessity of developing an organization of such elasticity that its provisions would not interfere with the development of the radio art.

The Madrid Conference, held in 1932, was primarily concerned with furthering interference reduction. The service bands were extended upward from 23,000 to 30,000 kcs. Recognition was given to the rapidly expanding air communications and provision was made for additional communication facilities for this new service. In the European area, the chaotic breadcasting conditions were recognized and an attempt was made to make available additional channels below the distress band for broadcasting in Europe only.

From a marine point of view, it is interesting to note at that time the recognition of the effectiveness of high frequency communications for mobile stations and recommendations were incorporated in the radio regulations to utilize certain specific high frequencies with a view to decreasing interference and providing international high frequency channels which might prove useful for long distance communications.

The International Consulting Committee on Radio.

The Washington Convention provided for the establishment of the International Technical Consulting Committee on Radio Communications, whose purpose is the formulation of opinions and advices on technical and related questions pertaining to radio com-

munications which may be submitted to it by participating administrations or private enterprises. This Committee was to meet between Treaty conferences. It is limited to giving advices on questions which it has studied and to transmitting those advices to the International Berne Bureau of Telecommunications, to be communicated to the participating administrations and private enterprises concerned, particularly with a view to determining technical standards for use as a basis at the following treaty conference.

Among the principal opinions rendered by this Committee has been a definition of widths for communication bands required throughout the radio frequency spectrum for various types of services. It has also defined what may be reasonably expected, from an engineering point of view, regarding the tolerance and stability of a radio transmitter, has established frequency standards and degrees of precision of frequency transmitters. The Madrid and Cairo Conferences recognized the valuable work of this Committee and many of its opinions have been incorporated in the radio regulations. This International Technical Consulting Committee held meetings at The Hague in 1929, in Copenhagen in 1931, in Lisbon in 1934, and in Bucharest in 1937.

International Telegraph and Cable Conventions.

The first treaty governing Telegraphs and Cables was a result of a convention in St. Petersburg, Russia, in 1875. This provided for the organization of the cable and telegraph facilities of the nations into a system for handling international traffic, by providing rules and regulations governing the exchange of traffic and for settling international accounts.

In 1908 the Telegraph Treaty was revised at Lisbon. This revision was much more detailed than the St. Petersburg's treaty, and included rules for the classification of messages, priorities, commercial service, government and press messages, operating rules and procedure, accounting instructions, and call signals.

In 1912 the International Radio Telegraph Conference in London made the provisions of the International Telegraph Treaty applicable to international radio telegraphy.

The Third International Telegraph Convention was held in Paris in 1925, and the Fourth at Brussels in 1928. The Paris conference provided for the exchange of telegraph and radio traffic at coastal radio stations.

At Madrid the International Telegraph Conference was, for the first time, held concurrently with the Radio Conference and the final result of the work was a combined Telecommunication Convention.

In 1934 and 1938 the Telegraph Conferences were held at Madrid and Cairo, respectively, in conjunction with the Radio Conferences.

Bureau of the International Telecommunications Union.

Naturally, in such a complicated world, there must be uniformity of effort, documentation, and circulation of proposals and treaties, call books, frequency lists, etc., which must be handled uniformly by one office in some one country. Accordingly, there exists, for this purpose, by provision of the Telecommunication treaty, a central office at Berne, Switzerland, known as the Bureau of the International Telecommunications Union, supported by the nations.

Procedure Prior to Conference.

It is of interest to note the procedure necessary to prepare for and to conduct a conference of this nature, as follows:

One of the concluding acts of each conference is to fix the time and place of the next meeting. The place is selected by the delegates, who vote as a preference for some one nation, the choice being limited to those nations who have expressed a willingness to act as host for the next conference. The treaty is then signed by the delegates. Some countries require ratification or approval by higher authority, such as in the United States by the Senate. The Berne Bureau then publishes and distributes the treaty in book form.

One year and a half before the next conference the proposals of all governments covering changes recommended in the treaties must be submitted to the Berne Bureau, where they are put into

French and English and issued to all the nations in book form. This distribution is accomplished in sufficient time that the administrations will have before them the proposals of all other nations for study at least one year before the conference meets. The administrations thereupon study these proposals, modifying their own as may be desirable. In the United States the preparations for all such conferences are carried on under the chairmanship of the Department of State, with the cooperation of the other interested departments of our Government and of civil interests. These preparatory meetings occupy months of constant work.

About a year prior to an international conference there are held a series of conferences between groups of nations and groups of individuals whose interests are more or less in common. For example, prior to the Cairo Conference were held conferences between North American nations on broadcasting, in Ottawa, between representatives of all Western Hemisphere nations in Lima, on air navigation aids and aeronautical radio, and finally one in Havana to consider the position of all American nations on all proposals to be considered at Cairo. Similarly, preliminary conferences of interested groups were held in Europe on broadcasting, aeronautical radio, and maritime radio.

From the foregoing it is evident that by the time of convening the delegates from all nations are fairly well prepared, not only in their own and foreign proposals, but also in the knowledge of how their proposals will be received by delegates from other nations.

It is customary for the delegates to arrive about a week before the convening of the "Telecommunications Conference," three or four days prior to the convening of the smaller conferences, in order to get settled, get acquainted with some of the foreign delegates with whom advance discussions may be desirable, and to study comments on proposals which may have arrived since departure from home. Also, there is the usual maneuvering for committee chairmanships, memberships, space, etc., such as takes place in any large assembly.

Arrangements at Place of Conference.

All arrangements for the meetings are the responsibility of the host government. This includes information to the delegates prior to arrival, arrangements for convention halls, subcommittee and staff rooms, mail and banking offices, sight seeing and entertainment schedules, and like matters. Usually the delegates find it advantageous to live as near the convention hall as possible. The host government has the valuable assistance of the experienced officers and staff of the International Bureau of the Telecommunications Union, from Geneva, which takes immediate charge of all clerical and translation work, and distribution of documents within the conference.

Various Points of View Represented.

A conference of this nature is not unlike a session of our own Congress. There is the organization, the parliamentary procedure, and the delegates with assistants, and staff, bent on putting through the proposals of vital interest to their respective nations. The interests of the nations are varied. The largest group, particularly the smaller nations, are interested mostly in local broadcasting and some in international broadcasting on high frequencies. The next largest group, perhaps the strongest, comprises nations which, like the United States, have large interests not only in broadcasting, but also in aviation, merchant marine, the Army and Navy, police radio, amateur radio, and domestic radiotelegraph service. This group is determined to keep its feet on the ground and try to push for progress within reason, as distinct from many who wish to give all the advantage to one type or other of service. Nations like the United States and Japan, for example, are not so influenced to make compromises for expediency as are the European nations, who are closely crowded together.

Considering the brief duration of such a conference, and the language difficulties, the difficulties of readily understanding the points of view of the various nations represented, and the entertainment schedule, it is a marvel what good results are obtained. This is due to a universal determination to agree, to live and let live, as it were.

Entertainment.

Entertainment is no small item. Host governments vie with one another to make the visitors comfortable, to provide social entertainment in the way of banquets, tea and cocktail parties, and special theatre performances for the delegates and families. But most important in this line are the sightseeing excursions, where one sees the historic and other famous monuments, resorts and edifices under the most favorable circumstances. At Cairo, for example, there was an automobile excursion each week-end to such places as the Pyramids, Mosques, Memphis and Sakara, Old Town, and by river boat on the Nile. Most of the delegates spent a week-end also visiting Luxor, Thebes, Karnak and the Valley of the Kings, and another motoring the length of the Suez Canal. When at Bucharest, the delegates were taken on a two days' trip on the Danube, on the King's yacht. Such excursions are not only wonderful in themselves, but in addition, provide a means for bringing the delegates and families into close personal contact, which is essential to the success of the conference. Usually about half of the delegates have attended previous meetings, consequently already are acquainted.

Frequency of Telecommunications Conferences.

Although the public generally follows the course of some of the more important political and economical international conferences, through the newspapers very few people have any idea of the number of international technical conferences which are constantly taking place. The "Journal des Télécommunications," official quarterly publication of the Bureau of the International Telecommunications Union, lists thirty-five, for communications alone, as having been concluded in 1937. Probably four-fifths of these were on regional matters pertaining to Europe only, where, due to the close proximity of nations and to government ownership of communication systems, more frequent conferences are necessary than in the Western Hemisphere.

The following is a partial list of future International Telecommunications Conferences already scheduled, which are of interest to all nations:

Name	*Next Meeting*
International Consulting Committee on Telegraphy (C.C.I.T.) (to revise technical standards)	Lisbon, 1940
International Consulting Committee on Telephony (C.C.I.F.) (to revise technical standards)	Lisbon, 1940
International Consulting Committee on Radio (C.C.I.R.) (to revise technical standards)	Stockholm, 1940
Inter-American Radio Conference (in preparation for the 1942 Rome World Conference)	Santiago, Chile, 1940
Inter-American Technical Aviation Conference (in preparation for the 1942 Rome World Conference)	Santiago, Chile, 1940
International Scientific Radio Union (U.R.S.I.) (non-government, scientific papers)	Paris, 1940
International Broadcasting Union (U.I.R.) (in preparation for the 1942 Rome World Conference)	Switzerland, Mar. 1939
International Radio Aeronautical Committee (C.I.R.A.) (to assist in making effective the last World Conference and to discuss preparations for next World Conference)	Paris, May, 1939
Central American Regional Radio Conference (to work out details for the Central American region, as laid down by the last World Conference)	Future
International Radio Conference	
International Telegraph & Telephone Conference (the next treaty conference on Telecommunications)	Rome, 1942
International Radio Maritime Committee (to smooth out details as a result of changes made at Cairo)	Future

The Cairo Conference.

The appropriation for our delegation to the Cairo Conference was $75,000, made to the State Department by the 75th Congress. The delegation comprised Senator Wallace H. White, Jr., Chairman, and three other delegates, one each from the State and Navy

Departments, and the Federal Communications Commission, nine advisors from War, Navy, Coast Guard, Commerce, and the Federal Communications Commission, together with a secretariat of twenty-two, including translators and stenographers.

The inaugural session on February 1, 1938, was opened by His Majesty King Farouk. The Presiding Officer was His Excellency Hassan Sabry Pasha, Minister of Communications. Mr. John Webb, Inspector of Posts and Telegraphs for Egypt, was the Chairman of the Radio Conference, and Mahmoud Chaker Mohamed Pasha, Chairman of the Telegraph Conference.

With a staff of nearly 100 assistants, our hosts spent a year in advance of the opening date, in preparation therefor—this, of course, in addition to their regular duties.

The work of the Conference was divided as follows:

Telephone and Telegraph Conference Committees: Telegraph Regulations, Telegraph Rates, Telephone Committee, Drafting, and Committee on the Examination of the Management of the Bureau of the Union (for the Telegraph Conference).

Radio Conference Committees: Regulations, Rates and Traffic, Technical, Drafting, and Committee on Examination of the Management of the Bureau of the Union (for the Radio Conference).

Each Committee was assigned a list of proposals for modification of treaty articles, and promptly sub-divided into subcommittees for carrying on the work. As soon as a subcommittee completed revision of an article, report was made to the main committee which passed upon the subcommittee's recommendations.

Telegraph Conference.

The proposals of principal interest to the Delegation of the United States were on those matters which affected the charges to be paid by the users of the international telegraph service and those proposals which affected the revenues of the Ameriran telegraph companies. These proposals related (1) to the unification of rates for plain language, cipher language and code language messages, (2) to the notification of the equivalents for the gold franc which

is used as the unit for the composition of rates and the establishment of international accounts, and (3) to the minimum number of words to be charged for in each class of telegram.

The Madrid Telegraph Conference provided for the following major classifications of public telegraph correspondence in the extra-European region:

1. *Full Rate* (plain language and cipher language) at the basic rate.
2. *CDE* (code language) at 60 per cent of the full rate charge.
3. *Urgent Full Rate* at double the full rate charge.
4. *Urgent CDE* at double the CDE rate charge (1.2 times the full rate).
5. *Deferred* at one-half the full rate charge.
6. *Letter Telegrams* at one-third the full rate charge.

Many administrations were of the opinion that it is not equitable to charge the users of the *Full Rate* category at the basic rate and the users of the *CDE* category at 60 per cent of this rate. They also believed that, if the two classes were unified into one category, the work of the telegraph administrations would be considerably simplified. For these reasons there were numerous proposals presented to the Conference for the unification of telegrams in plain language, code language and cipher language.

These proposals were divided into three major groups as advocating:

1. Unification at 60 per cent, the elimination of the *deferred* classification, the maintenance of the existing ratio for *urgent* telegrams and of the existing actual rate for *letter telegrams.* This proposal was made by Germany and was supported by 21 administrations.

2. Unification at 66⅔ per cent, *urgent* telegrams at one and one-half times the new rate (the existing full rate), *deferred* at three-fourths the new rate (the existing actual rate), *letter telegrams* at one-half the new rate (the existing actual rate). This proposal was made by Great Britain and was supported by 12 administrations.

3. The maintenance of the "status quo" supported by 12 administrations, including the United States.

The first two proposals failed of sufficient support, therefore the third proposal or the " status quo " in regard to the charges for plain language, code language and cipher language was automatically maintained for world wide international services.

In discussing the questions of unification and of the rates to be charged the public, the Conference was vitally concerned with the equivalent of the gold franc fixed by each administration for the collection of the charges in its own country, as prescribed by the Telegraph Regulations. At the present time, this is not universally applied because more than 30 administrations reserved on this article in the Final Protocol to the Madrid Regulations.

Many administrations proposed that these reservations be withdrawn and that each country collect, in its own currency, the proper equivalent of the gold franc charges so that the rates between any two countries would be the same in each direction, but were unsuccessful.

The United States has never signed the International Telegraph Convention, because of the fact that it was felt best to allow its own private companies to make their own arrangements direct with foreign companies, mostly government monopolies. However it is probable that in the very near future the United States will at least adhere in part to this treaty if not sign and ratify it, because the situation as it stands has become unsatisfactory to certain groups in the United States as discrimination is charged, and because, unless the United States signs the treaty, it cannot play as forceful a part in the deliberations.

Radio Conference.

The General Radio Regulations annexed to the International Telecommunications Convention of Madrid have in general been satisfactory to the United States. However, the ever-increasing demands for additional radio frequencies due to a never-ceasing expansion of the mobile, fixed and broadcasting services necessitated a further tightening of existing rules to make the most economical use possible of facilities at present available, as well as a reconsideration of the existing allocation of frequencies in the light of experience gained since the Madrid Conference.

The following are some of the more important decisions of the Cairo Radio Conference which have been incorporated in the Revised Regulations adopted at that Conference:

1. ADOPTION OF A PLAN FOR RADIO CHANNELS FOR THE WORLD'S SEVEN MAIN INTERCONTINENTAL AIR ROUTES, INCLUDING CALLING, SAFETY AND SERVICE CHANNELS.

Because of the rapid expansion taking place in aviation throughout the world and the immediate prospect of scheduled air transportation across the Atlantic, the Conference was eager to provide radio frequencies which would fulfill the needs of the future aeronautical service.

Early in the Conference it was found possible to dispose of many of the controversial questions relating to aeronautical services which utilize frequencies above 1500 kc. by eliminating discussions about the use of radio within a nation's borders and confining discussions to strictly common problems involving overseas and long distance international air services which, for convenience, were referred to throughout the negotiations as "intercontinental operation." As far as the domestic air services in the United States are concerned, the situation was complicated by the extensive use therein of high frequencies of the order of 5000-6500 kc. which are recognized as having long distance characteristics and which had to be considered in any allocation plan for intercontinental air routes.

On frequencies above 6000 kc., the European nations under the active leadership of Germany, Great Britain, the Netherlands, France, and the Union of Soviet Socialist Republics pressed for a relatively wide band in each portion of the spectrum which they proposed to clear for exclusive use of the aeronautical services. The United States recognized the needs of intercontinental air services and indicated a desire to cooperate to an extent consistent with our interest in the matter, but opposed the allocation at this time of wide and exclusive aeronautical bands because of the difficulty of displacing existing stations of other services which might not be able to find satisfactory replacement frequencies, especially in the congested portions of the spectrum. The United States delegation suggested that specific "Spot" frequencies be selected

for each intercontinental air route, such frequencies to be in various spots of the spectrum because of their particular characteristics for the distance and service requirements. This idea was accepted, as will be seen in the general allocation table in the Treaty which deals with the allocation of frequencies to intercontinental air routes. In addition, and as a compromise to satisfy the desire for exclusive aeronautical bands in certain regions of the world, the plan permits secondary use of the same bands in which the intercontinental frequencies are designated, in Europe, the Union of Soviet Socialist Republics, Africa, and South America.

Allocation of exclusive, or at least protected, aeronautical bands, especially in European regions, was admittedly necessary because of the wide diversity of national aviation policies in so many relatively small countries and to the resulting and insuperable interference problems. Under such conditions, it is utterly impossible to protect spot frequencies adequately from interference as can be done in the United States, where a single administration exercising strict control over all airways and other non-governmental services can take full advantage of geographical separation and other factors which permit economical use of all bands of frequencies by all services.

After over two months of intensive work, mutual agreement was finally reached on a compromise plan which satisfactorily reconciled the various viewpoints with respect to intercontinental and regional operation. As far as the United States is concerned, its views concerning specific aviation frequency assignments, instead of allocation of bands with operation at will throughout those bands, were met by the designation of precise frequencies on an approximate 0.1 per cent channeling system for each intercontinental air route, on the basis of protection of operations on that route only and under much more rigid frequency stability tolerances than had first been proposed. The desire on the part of Europe, the Union of Soviet Socialist Republics, Africa, and South America, for bands of aeronautical frequencies was, in effect, met by selection of groups of specific route frequencies which are contiguous in sufficient number actually to constitute small bands. This had the advantage of permitting the removal from aeronau-

tical bands of all other services in these regions, while at the same time permitting important stations of aeronautical and other services in the rest of the world to continue operation on their present frequencies.

These intercontinental air routes were:

(1) Transatlantic.
(2) Inter-American.
(3) Europe—Asia—Australia.
(4) Europe—Africa.
(5) Europe—South America.
(6) Europe—North America (via Arctic).
(7) Transpacific.

It was agreed to designate two aeronautical service general calling frequencies: 333 kc. for short distance operation where it is desired to employ direction finders on the ground, and 6210 kc. which is technically better adapted to aircraft use over greater distances usually involved in international operation. Meteorological broadcasts were to be provided for in the other service bands, as is now the practice in the United States.

Frequencies for blind landing and marker beacons were adopted.

2. WIDENING OF THE HIGH FREQUENCY BROADCAST BANDS TO A TOTAL OF 300 KILOCYCLES AND THE ADOPTION OF SPECIAL BANDS FOR TROPICAL REGIONS FOR REGIONAL USE.

In considering the needs of broadcasting services the work was divided up under five general headings, viz., long wave broadcasting, regular medium frequency broadcasting, tropical broadcasting, high frequency broadcasting over long distances, and broadcasting (including television) on frequencies above 25000 kcs.

For long and medium wave broadcasting, the only changes were regional, and did not affect the United States. In fact, these changes tended to bring the European allocations more into conformity with those of this country.

A very thorough study was made of the possibility of time sharing and simultaneous use of broadcasting frequencies between 6000 and 25,000 kcs. This study will be valuable to nations which have been unable to obtain frequency channels for this service, as it permits them to occupy channels elsewhere in use, if they can do so without interferences to existing service.

The present high frequency bands are much too narrow to permit each nation even one high frequency broadcast station, and many nations, especially the smaller nations, recommended widening these bands to permit each to have one set of harmonically related high frequencies. The larger nations already occupy nearly all of the frequencies allotted to high frequency broadcasting, and other nations have occupied channels in non-broadcast bands for broadcasting because of necessity. Some of the demands were for long distance broadcasting intercontinentally and some for national broadcasting in countries so large that the low frequencies did not provide sufficient geographical coverage, where sparsity of population did not make it economically feasible to install wire lines, and also where static made useless broadcasting stations of reasonable power output. The widening of the high frequency broadcast bands by about fifty percent was agreed to, with the understanding that the broadcast stations occupying non-broadcast bands would be moved into the new extensions to the regular broadcast bands. Also, special high frequency bands of frequencies of limited ranges for broadcasting were authorized for tropical nations, under certain restrictions as to power output and non-interference with mobile services. Provision was made for future regional conferences to be held locally, between nations within the affected regions, to work out the details for tropical broadcasting. Already one of these has been held in Guatemala City between the Central American group.

3. THE LIMITATION OF THE USE OF SPARK SETS TO THREE CHANNELS (INCLUDING THE DISTANCE AND DIRECTION FINDER CHANNELS) AND THE OUTLAWING OF SPARK SETS EXCEPT BELOW 300 WATTS OUTPUT.

The United States, supported by several other countries, advocated the total elimination of radio traffic on the 500 kc. distress frequency for other than distress, urgent and safety measures. This same proposal had been made at the Madrid Conference and, while it was strenuously opposed by certain countries at that time, regulations were adopted by that conference which restricted somewhat radio traffic on that frequency. France vigorously supported the proposal as renewed at Cairo, but Great Britain, sided by other

maritime nations including her Dominions and northern European countries, was instrumental in defeating it. However, an agreement was reached imposing further restrictions upon the use of 500 kc. for the handling of traffic. The proposal had for its purpose the reduction of interference caused by the excessive use of the frequency for sending messages, thereby preventing distress and urgent calls from being heard. Under the new regulations, ships in regions of heavy radio traffic, equipped with break-in devices, may transmit only one short single message on 500 kc., thus, coast stations and many ships will no longer be permitted to use this frequency for radio traffic for even short, single messages, as under the former rules. In other regions it may be used for traffic and radio direction finding, but with discretion. Further real progress has been made, therefore, toward the elimination of interference on the distress frequency.

4. GREATLY IMPROVED FREQUENCY TOLERANCE AND BANDWIDTH TABLES.

These will result in very considerable reduction of interferences, but are still far from adequate to satisfy the needs of the nations.

5. ALLOCATION OF ULTRA-HIGH FREQUENCIES.

For the first time allocations of frequencies were made to services in the newly developed portion of the radio spectrum from 30,000 kcs. to 300,000 kcs. known as ultra-high frequencies. These were made to include, for the first time Television; also fixed, mobile, amateurs, airport control, aeronautical, blind landing, marker beams, other navigational aids, and broadcasting. The allocation of ultra high channels for the American Continents is to be used as a basis for future research and experiment, whereas that of the rest of the world was adopted on a permanent basis.

Amateur Channels.

Notwithstanding the efforts of our delegation, the amateur frequency bands were slightly narrowed by the Cairo treaty. The preponderance of interest in amateur radio is in the Western Hemisphere, especially in the United States which has about 50,000 licensed amateurs, out of a world total of roughly 60,000. The

majority of nations, either not being particularly interested in amateur radio or altogether opposed to it, advanced arguments to the effect that the need of additional frequencies for broadcasting was so great that the amateurs could best make the sacrifice. The United States has always championed the cause of the amateur, as we believe the amateur is extremely valuable in technical development work,—this has been proved—, and that the education of young amateurs through building and operating their own equipment is very much worth while.

Ultra-High Channels.

Television. The United States' delegation endeavored to obtain worldwide agreement to adopt certain ultra-high frequency bands for television, each with an aural broadcast channel, at least for research and experimentation, hoping in this way that the world's television bands would ultimately become standard. This would have paved the way for uniformity in design of equipment. But we were unsuccessful in this, except in so far as concerned the Western Hemisphere. The fact that several thousand television receiving sets were already in use in Europe,—England especially, and that these would not operate in the bands decided upon by the Americas, made it impossible for Europe to accept our proposal to agree on bands which, in the light of recent technical developments, were much superior to the bands already used in Europe.

Meteorological Services.

A new service in radio is the automatic radio weather data service broadcast by miniature radio sets on small balloons (radio sounding service) and received at ground stations from which they are released. For reasons of radio interference, and in order to permit standard designs of equipment, this type of service was provided for definitely in the radio spectrum.

Miscellaneous Allocation Matters.

MARITIME SERVICES PROTECTED

In the band from 10-550 kcs. the fixed and maritime mobile services will continue to enjoy the same rights as heretofore, except in Europe where the maritime service will no longer use

frequencies 395-415 kcs., also Japanese small ships on low voltage spark sets may use 1364 kcs., not to interfere with other services.

DIVIDING LINE BETWEEN REGIONAL AND LONG DISTANCE HIGH FREQUENCIES.

The dividing line between frequencies recognized as valuable for long distance communications and of regional value only was changed from 6000 to 5000, in recognition of engineering facts.

AIRCRAFT REQUIRED TO CARRY SOS EQUIPMENT OVERSEAS.

Aircraft flying over maritime routes are required to carry equipment enabling them to communicate on the distress frequency, 500 kcs., for communication with surface ships and coastal radio stations.

Improvement in Operating Rules.

The operating regulations of the treaty were improved, based on experience, but no changes of a major nature were made.

Considerable sentiment developed to remove from the General Radio Regulations any provisions relating to aircraft, on the theory that the aeronautical organizations should be permitted to draw up their own radio rules of procedure. It was argued that the former regulations applied principally to maritime radio communication and that these procedures were not applicable to the fast-moving and expanding aeronautical services, in view of the dissimilarity in operation between the two. The United States could not agree to this position. While it is true that the regulations were originally evolved from the maritime problem and the regulations still remain predominantly maritime, the other mobile services are adequately provided for. The United States believed also that the regulations could be so written and expressed as to provide for the ordinary international contacts, leaving it to regional agreements between interested governments to take care of local conditions and problems. This view finally prevailed and it will be found that in various articles the aeronautical service has been given separate sections. Whenever it developed that a general rule might not meet all conditions throughout the world, the various countries concerned are left free to regulate the particular aeronautical problem by regional agreement.

One important article of the previous regulations provided that the master of a mobile station, such as a ship or aircraft, should have supreme authority over the radio station, a principle which was well recognized by everyone. However, in the discussion at Cairo there appeared to be some doubt as to whether an obligation was implied to carry out the radio regulations. In order that there would be no misunderstanding, a provision was inserted that the master, because of his supreme authority, has the responsibility of seeing that the general radio regulations are carried out by the radio operator.

The regulations were changed slightly, based on experience with the automatic alarm for SOS, and to require that a ship in distress transmit its call signals followed by the distress message for a period sufficiently long to permit direction finder bearings to be taken. Some of the abbreviations used in radio, ordinarily known as "Q" signals were changed, also the list of definitions brought up to date due to new types of services such as facsimile and television. Some changes in standards of ship and aircraft operators' certificates were agreed upon.

An important new principle, in connection with registration of frequencies, was agreed upon, which shows that the notification date in the Berne Bureau frequency list is actually a priority date for the country as a whole, rather than for a particular station.

LANGUAGE.

At former Telecommunications Conferences, the Secretariat of the Conference, under the Berne Bureau, provided translations of minutes and documents only in French. This necessitated augmenting the United States delegation with an expensive staff of translators and stenographers, in order that its delegates be promptly furnished English translations. As a courtesy these, being mimeographed, were habitually furnished to other non-French speaking delegations. At Cairo these English translations were requested by 44 delegations, which unjustly centered an expensive burden on the United States. In appreciation of this voluntary service, these forty-four delegations signed a petition recommending that hereafter the Berne Bureau supply the necessary translations and documents in English as well as French, all the nations requiring such

documents to share the expense. As a result, it will be unnecessary for the United States to send a large staff with future delegations to International Telecommunication Conferences.

Subsequent Regional Conferences.

Already, within eight months since the close of the Cairo Conference, regional conferences have been concluded to take advantage of opportunities made possible by the Treaty for local groups of nations and for services to cooperate in increasing the effectiveness of their radio, in so far as such action will not adversely affect other nations, or services. One was held in Paris in November 1938, known as the Third World Conference of Radio Telegraph Experts for Aeronautics, primarily to discuss time schedules and other details concerning the use of the air route frequencies assigned by Cairo; a second at The Hague in October 1938, to arrange details concerning the operation of low power radio telephone services in the North Sea—Baltic area; and a third convened at Guatemala City in November 1938, to allocate regional broadcast channels assigned by Cairo among the Central American nations, including Panama and the Canal Zone.

Already studies are being made and proposals are in preparation throughout the nations for distribution through the International Communications Bureau in anticipation of regional conferences preparatory to the next World Telecommunications Conference to be held in Rome in 1942.

THE GAS TURBINE CHALLENGES.

By Lieutenant Commander Warren Noble,
U. S. N. R., A-V (S).

For many years engineers have speculated on the advent and possibilities of a useful gas turbine. A short article by W. E. Trumpler, entitled "The Combustion Turbine," appeared in the February, 1935, issue of Power on pages 78 to 80. This article included a description of the actual apparatus together with operating efficiency and other data.

In the present paper, the author makes a preliminary survey of the application of gas turbines in the marine field. He derives a skeleton structure which he predicts will be completed at an early date by filling in the essentials of practicable design and construction technique.

Once upon a time a gentleman named Hero built a fire under a pot-bellied swastika half filled with water and watched it presently begin to spin upon its axis to the wonderment of the beholders and doubtless of Hero himself, who didn't know what to do with it. The first steam turbine of record, it wasted its wonder upon an incurious world and transmitted its message to posterity mostly as a stereotyped illustration in textbooks on natural philosophy. As the ages wore on, the windmill and the water wheel, turbines both, took up their part of the world's work to be temporarily displaced centuries later by the reciprocating steam engine.

De Laval made some stir after a while with a tiny turbine wheel operating at fantastic speeds and so made ground for more conversation than consideration by serious engineers. Then came Parsons, who whittled a turbine that ran fast—but not so fast as to be entirely beyond the imagination of the budding electric designer who sensed in it the possibility of reducing generator bulk.

I was an apprentice boy in a locomotive works when the *Cobra* and *Viper* were built for the British Admiralty—made the trials so full of both tragedy and triumph—an engineering student when the elements of turbine building became the theme of a myriad of half baked text books by quarter baked professors who had sneered at turbines two years before. Naturally, having watched the victory of rotary over reciprocator in almost every field of steam use I, in common with every other constructor, have loose-tongued the prediction that someday—someday—there will be a gas turbine.

Even in a world that takes only an average of twenty years to absorb and adopt any unsubmersible idea, it has seemed to be a long time coming. Our attention has been so much diverted to the perfection of internal combustion engines, large and small, that the advent of the gas turbine, the true rotary internal combustion engine, has been missed or ignored by the very constructors who should have been first to follow its star.

Sir John E. Thorneycroft's presidential address to the Institution of Marine Engineers in 1937 on the advances in marine propulsive plants during the last twenty-five years emphasized almost dramatically the ever diminishing return of engineering development in an intensively cultivated field.

If you have been unfortunate enough to miss it, a paraphase of its content would point out that at the expense of infinite ingenuity, comprehensive scientific attack, almost unbelievable complication and crowding in the engine room, plus the questionable military advantages of red hot steam pipes and super steam pressures, a truly insignificant improvement in speed and range of naval vessels had been accomplished. Certainly it left one with the feeling that Thorneycroft, with unparalleled experience in the building of high performance naval power plant machinery, saw very little further to go along the chosen path.

Remembrance of the chosen path as the "via dolorosa" of less than thirty years ago, the learned objections of the powers-that-were to sacrifice of "proven practice to new fangled and obviously dangerous experiments with turbines," makes me wonder if the desire to climb the band wagon once the parade has started is not the strongest of human weaknesses.

Unfortunately, one can't let the gas turbine alone any more than Parsons could be let alone. The gas turbine is here! What is more, it has been here for several years doing its job unobtrusively, gaining the confidence of its constructors, making converts as slow comprehension dawned, lacking nothing, it would seem, but a publicity campaign to make the world conscious of its merits, potentialities and limitations. Fathered, fostered, fought for by Dr. Adolph Meyer, the dynamic Thermo-Dynamic Division director of Brown Boveri et Cie. of Baden, Switzerland, it now commands a most significant position as power generator. Standby and emergency bombproof electric plants capable of immediate assumption of full duty have become a prime necessity of military preparedness. In Europe the gas turbine has supplied the answer either directly in its proper person or indirectly as the lungs of a Velox boiler, which first came into being through an attempt to cool the combustion chamber of an experimental gas turbine by protecting its walls with water tubes. So startling and important were the results of that experiment that it culminated in the Velox boiler, itself a highlight in the history of steam generation. An ultra commercial product, despite its novelty, it provided the sinews of further development and an unobtrusive field of proof for the gas turbine.

Every Velox boiler is the antechamber of a gas turbine where air under pressure is burned by injected fuel. The *stack* gas is passed through a turbine that drives the compressor and other auxiliaries to supply the boiler. The turbine run by the stack gas is certainly a gas turbine.

In my thirty years of professional experience as a consulting engineer I must have been coaxed and paid—mostly coaxed, because the very idea of a gas turbine closed every angel's pocketbook automatically—to look at and criticize at least a hundred projected gas turbine designs. Of them all, not one survives in my mind. Students of the Patent Gazette have seen hundreds of abridged specifications to be scanned and dismissed almost at a glance. Only the name of Holzwarth has persisted through the years; to leave a flavor of appreciation of perseverance and a certain wonder that the occasional rumors of operating installations seemed to lack corroborative vitality. So when, on a recent visit

to Dr. Meyer in Baden, the gas turbine, in active production, on the right side of the ledger in powers to be spoken of respectfully, burst upon me as it were; it came as something of a shock.

Here was a major engineering development quietly grown to man size, doing a job of work in simple, straightaway fashion, entirely beyond the chance taking stage, obviously being appreciated by the cognoscenti (since the shops were full of machines in various stages of completion for delivery to various parts of the world) yet, as far as I knew, completely unknown to the engineering fraternity with which I was best acquainted. Here, no matter how hard one rubbed the eyes, was the gas turbine—no fearsome red hot complex affair but a nice docile, noiseless, slick running machine that might for all the world be a particularly smooth steam turbine set. But what there was was all there was; not the annex to an acre of boiler house, with an attic full of steam pipe and a cellar full of condenser but just all there was. None of us had caught up or caught on, whichever way you like it best.

As I stood there looking from the machine on the test floor, steady as a clock at 6000 turns, to the opened case of its mate across the aisle, that looked for all the world as if somebody had started to make a few stages of a particularly simple and sturdy turbine just to show what a turbine looks like, there crept into my mind a vision of an engine room of the near future—an engine room so simple that clear space existed about the clean barrels of the main engines; and when I started to fill in the auxiliaries and ghost in the pipes and see where all the gadgets could be placed, I suddenly realized there wouldn't be any pipes and there needn't be any gadgets and the original quick vision was all there was—there just wasn't any more.

On the way back to Zurich I fell to wondering what we could do with all the extra space that happened when there wasn't any boiler room and how to make up the weight so as to leave the water line where it ought to be and from there to a thousand and one things we never really thought about at all before (because what was the use) and so on to the idea that somebody ought to do something about it all—soon. So I'm telling you!

Enough of the crystal gazing. Let me tell you how it's done, what it can do—what the potentialities appear to be—the worst

about it and the best, without being too technical. Dr. Meyer has a date to tell the complete story to the A. S. M. E. shortly, and his flair for the simplification of simplicity will give you all the abstruse details in digestible form. If I can prepare his way ever so little I shall be happy enough.

His gas turbine is a continuous as distinct from an intermittent combustion machine. Air is compressed continuously—fuel is injected into the air continuously—the heated air thus enormously increased in volume, drives both compressor and turbine continuously.

That is the whole story, it's that simple, but the technique of the construction is a triumph of detail handling. The key to success was forged when the rotary compressor climbed to a higher efficiency than ever before achieved. As long as the overall efficiency of the compressor and its driving turbine stayed around the 50 per cent mark there was nothing left over for usable power from the heated air. As the losses of the compressor unit were reduced the usable power rose and rose fast.

A gas turbine for ship propulsion is actually two entirely separate machines although a physical enclosure in a common case may prove convenient. The compressor is integral with and driven by its own gas turbine being started from a separate source of power demanding a very small percentage of the normal input. Once turning over and so passing air to the combusion chamber, the fuel, which may be oil or gas or anything burnable for that matter, is fed into the air, and so burned, increasing the air temperature, volume, and velocity through the turbine blading thus brought to a speed commensurate with the fuel consumed at a pressure similarly determined. There is no increase of pressure over that supplied from the compressor in the combustion chamber, only increase of air volume, a direct function of the fuel consumption rate. The speed of the turbine depends on the number of stages selected—the number of stages on the selected heat drop per stage. Ordinarily the number of stages will be from five to seven; the pressure about 60 pounds per square inch maximum. This pressure varies naturally with the load as does the temperature. All the ordinary laws of turbine design obtain—the most efficient speed is half the gas speed—the staging is designed to

maintain this condition as the temperatures drop from stage to stage just as in a steam machine. The mechanical proportions with regard to diameter, blade length, etc., are more favorable than with vapor machines since the volumes are diminishing instead of increasing as where vacuum is employed; clearances may be greater. While blade temperature is high (actually no higher than with the primary stages of modern hot turbines) the shortness of the machine and relative uniformity of the drum makes for diminution of temperature derangement difficulty. It has been pointed out that there are actually two or more entirely separate machines, a gas turbine driven air compressor, a fuel injection system and one or more power turbines. The turbines may all be fed from a common combustion chamber although it is not essential for such to be the case. Thus the compressor turbine can have its fuel injection zone individual to itself—the power turbine similarly so. The pressure throughout the combustion chamber will be common although fuel may for convenience be burned at more than one location provided the air from the compressor or compressors is suitably distributed.

When we consider a ship layout—e.g. an ordinary twin screw installation we need conventionally four turbines—two ahead, two astern, if we eliminate the possibilities of either reversible propellers or gear changing. Each may have its own compressor or a common compressor may be used. The air pressure in either case becomes uniform and the air distributed with fuel addition at the individual turbine combustion chambers.

It is here necessary to explain the salient feature of final temperature control. The burning of fuel in the compressed air gives rise to local temperatures far too high to be used direct in turbines bladed with known material and by normal methods; so in order to reduce the final working temperature, the compressor is designed to deliver an excess of air sufficient to dilute the resultant melange of air and burned products, "the gas" to a safe maximum. Thus today Brown Boveri make a guarantee based on the power generated when the mixture registers 550 degrees C., a temperature attained with fuel oil combustion when diluted with substantially 400 per cent more air than required for perfect combustion of the fuel. Thus the compressor for a 20,000 HP turbine is actually

delivering air sufficient for a turbine of 100,000 HP were such a turbine working upon balanced combustion. Such turbines are indeed air cooled.

Since the fuel is invariably burned in a large excess of air excellent insurance against smoke production is afforded.

The problem of the ship installation is of course more complex than that of a simple electric generator driving machine in which a single turbine rotor can do the entire job. With unidirectional rotation the generator driving power is simply surplus beyond that required for the compressor. When the matter of reversing direction of rotation comes into the picture it complicates things to about the same extent that the astern turbine does with the usual steam plant or possibly a little more so, and much ingenuity is evokable to the end of simplification of this function.

An outstanding virtue results however from this division of the compressor element from the final power unit, since it determines the maximum available power as purely a matter of what temperature the blading will stand.

A few lines ago a "guarantee temperature" of 550 degrees C. was mentioned. This temperature has been exceeded already for such durations of service as to establish the 550 degrees C. rating as an ultra safe standard. It is found the power curve rises steeply with rising temperature, with startling improvement in overall efficiency since compressor economy and power surplus expand simultaneously. There is however no marked increase in working pressure; improvement is almost entirely volumetric; stepping up of output is not therefore accompanied by an increased risk as with a steam plant. This seems to be a strong argument for the gas turbine in naval application; since it affords a bounteous and reliable reserve of power without human risk for a short period of use, capable of being maintained over a long pull with no greater ultimate penalty than a reblading. In other words, if normal high speed operation is accounted for by 25,000 shaft horsepower, an extra 10,000 HP can be instantly made available, in case of necessity, without serious danger of mechanical breakdown, without danger to the crew and without permanent impairment of the future of the installation.

Is there any other source of power capable of such emergency response?

What of overall efficiency? Broadly it may be taken as parallel to the average well designed steam plant. At ultra high loads it is distinctly better—at normal high load about the same and in the lower ranges favorably inclined. It must not be forgotten that at cruising speeds the average steam plant is consuming well over fifty per cent of its fuel in driving auxiliaries which do not obtain with the gas turbine installation, a feature of considerable moment viewed either from the standpoint of economy of operation or from that of first cost. Speaking of cost—think of a ship without boilers, without condenser or pumps, deaerators, traps, gadgets, pipe mazes, gauges, fans, fittings and all the fancy work to which we have become accustomed. Even the turbine power units are of the simplest most robust type of construction—the compressor combinations even more so. True, such turbines require the use of expensive blading materials but don't they all nowadays? As to weight, take it as the same as a modern steam plant of equal power less boilers but don't forget the main machines are all there is. The weasel weights are absent.

As to the space requirements, the entire installation will barely fill the present engine room. The boiler zone and condenser space is all free. Could we use that extra room on a destroyer for example?

So many possibilities are opened up. No boiler condenser and auxiliary machinery—weights can be put back in the form of fuel—call it range with an extra spurt in hand. Only gas turbines on that ship. Or if you please the cruising speeds can be wished on to Diesels with the turbines left for the high speed work and life insurance. The extra room is gone—the weight is back but range can be doubled without sacrificing supreme high speed ability. Obviously there are other combinations but the simple single engine room has tremendous attraction.

To inspect a steam powered vessel using Velox boilers is to invite the subconscious feeling that half the ship must have been left at the dock, although in the engine room proper the changes are not apparent. No one yet has completely designed a gas turbined naval craft—I say completely designed to distinguish such

a project from the dotting in of some temporary lines on a set of hull plans. Actually nobody has yet completely designed any kind of naval vessel with a view to reducing it to the simplest possible terms with all its functions condensed in optimum relation each to each, to embody the simplicity that inevitably follows comprehensive envisualization of purpose unhampered by set forms, standard arrangements, obsolete equipment, contractual expediency, and contractor's connivance. We still swallow the jumble of auxiliaries and create a species of mechanical Christmas tree by adding this and hanging on that, while we're trying this out and wondering whether we are going to be able to get that in.

Such a complete design would be interesting. Maybe by the time it was done it would have to be modified and remodified to make it economically possible but the potential economies are worth thinking about and out of it would eventually come a vastly improved layout even though the ultimate condensation of the trimmings to the lowest common denominator might never get constructed.

The world is full of apparatus that has been forced through such a process of simplification, rarely from choice,—almost always in a frenzy of self-preservation but the end results are tremendously worth while. Because things must be cheaper they must be lighter, simpler; as they get simpler they become better; as they become better they become more profitable and so more susceptible to an increased rate of improvement.

This gas turbine potentiality will presently stumble along the hard way to fruition in spite of crossed fingers and the tongue in the cheek, probably via a makeshift installation patched into an old hull and expected to operate through obsolete reduction gearing. It ought, at the same time, to be taken seriously by a planning division on the presumption that its present importance in the world at large may make it an unavoidable factor in future naval construction. A ship should be designed to take advantage of its characteristics if, as and when the day can no longer be avoided. Such a design would serve its best purpose by enabling the idea to season itself in the professional arena, a process, in the end of more importance than technique already to hand.

The gas turbine practices heat conservation just as does the steam plant. The stack heat losses are partially caught by devices for heating the air leaving the compressor on the way to the combustion chamber. All the heat that can be saved is beneficial to the efficiency but in the end the atmosphere temperature line is the low limit to which the gas turbine must subscribe. The steam plant and the gas turbine vary relatively little in their ultimate economy—what the gas turbine may suffer inherently at light loads is more than made up by the absence of parasite power demands so expensively cumulative in the up-to-date steam installation.

It is not worth while contemplating gas turbines of low power. All the fundamentals of turbine design obtain unfortunately for the special case of the gas turbine. I say unfortunately because the nature of the working fluid in the case of the gas turbine is such as to preclude nozzling so that having determined the optimum compressor characteristics with respect to final combustion chamber pressure it is necessary to design the turbine from there on as having complete admission. Even cursory examination of the permissible heat drop per stage will indicate that little is to be gained by adding unduly to the number of stages. I believe I am correct in giving a rough estimate of 4000 HP as a minimum worth-while size.

Fortunately no probability of such low power per shaft need be entertained for Naval use. When however powers of 25,000 HP per unit and up are contemplated the proportioning begins to reveal the mechanical advantages (as distinct from the thermal characteristics) of the gas driven wheel since the final dimensions of the compressor drum and the wheel diameter approach each other within fairly narrow limits and a final case form of fairly constant diameter avoids the space wastage often engendered by the low pressure end of the steam prototype. The constructional details are definitely simplified; the weight space relationships are specially favorable. In ship engine forms, the shortness of the main engines is remarkable, the inertia of the wheels relatively low—the clearances of both turbine and compressor blading of comforting freedom.

Studies recently made of the essential weights provided some highly encouraging figures. While this article has refrained from

quantitative statements it may remark substantial reductions in overall mass, without departure from conventional materials and methods of fabrication, are easily in sight if contrasted with recent steam machines. Moreover the grouping can be happily arranged with regard to reduction gear case sizes with still further saving in weight and concomitant increase in stiffness.

There are several gas turbines of this general type in service or about to be put in service in the United States. The great oil companies have found in them a useful method of deriving process power with a surplus of electrical energy when fed with by-product gas from their cracking stills. The U. S. Licensee—one of the present builders of power generating machinery is about to make delivery of the first American built machines.

In Switzerland production of gas turbines of large size is proceeding with considerable urgency, to fill the demand for stand-by electric service bomb-proofed against aerial attack. The Velox boiler, also popular for this service and of ever increasing capacity is based upon supply of supercharging air from a gas turbine compressor set. These sets, many of which exceed 5000 HP in capacity, are being turned out daily. While the marine field for the direct gas turbine is only in its infancy the Velox boiler application finds favor in the Navies of four great Powers where its ability to assume full load from stone cold in less than five minutes is not the least of its spectacular advantages. The direct gas turbine application is already occupying the active attention of these same keen seekers for naval supremacy and it is the purpose of this article to call attention of naval engineers to the imminence of forced consideration of this type of propulsive machinery. If I am too general in my statements and found lacking in quantitative presentation I wish again to remind you that Dr. Meyer will shortly be with us on a visit to the United States during which he will present at first hand the fascinating facts and figures of a most remarkable twenty years of work.

To summarize the situation as I see it, we should pay serious attention to a new type of propulsive plant for naval vessels for which the following qualities may be claimed:

(1) Less space is required.
(2) Less weight is involved.

(3) A fuel economy substantially parallel to the present steam plant can be achieved.
(4) No high pressures of any sort are involved.
(5) A substantial reduction in cost is foreshadowed.
(6) An emergency high power of not less than 50 per cent above normal rating is available for a limited period.
(7) The engine room risks in action are minimized.
(8) Less engine room crew required.
(9) No water problem or change of performance with climate exists.
(10) No hot piping.
(11) No fuel consumption at anchor for propulsive plant standby.
(12) Full performance from stone cold within five minutes.
(13) More fuel can be carried without encroachment on useful space.

Against these virtues must be accounted the necessity for

(1) a completely new design with widely modified superstructure arrangements on account of large air volume requirements,
(2) ships auxiliaries with a separate central system for power,
(3) a starting system capable of about 1 per cent of the compressor rating also.
(4) There is as yet no naval vessel completed to provide prototype data.

None of these five objections appears to be very serious. The first is a matter which would require careful experimental work in actual rough water conditions before projection of a final design would be reasonable or possible. The second and third can be grouped as one problem and satisfied by a Diesel electric power plant or even another separate gas turbine plant. The last will probably make for a better end result than if opportunity to copy somebody else existed.

Ultra simple construction with gas turbines alone contrasted against the same high performance engine room plus a battery of internal combustion engines to take care of economy cruising will in the end find fields for both arrangements. It is conceivable that a four turbine ship—all gas with the cruising turbines adjusted to high-efficiency performance might provide an answer.

Should a national emergency arise with prime necessity for swiftly built, relatively cheap, fast craft the gas turbine plant would sweep the field on every count. There are no other internal combustion engines yet in sight capable of even approaching their power possibilities. The labor content of such craft would be overwhelmingly in favor of gas in place of steam turbines.

I trust this exposition, non technical as it is, will interest my readers sufficiently to create discussion and so prepare the way for Dr. Meyer to spread upon the record the statistics of his outstanding achievement.

INVESTIGATION OF THE ACTION OF CONDENSER SCOOPS BASED UPON MODEL TESTS.

By JOHN R. WESKE.*

The condenser scoop is endowed with an inherent simplicity of operation. Beyond this the several investigators of past years have not demonstrated in practice a superior method of scoop design. Recently, in a ship, the scoop lip was removed after several years at sea. The suitability of flow characteristics did not decrease. Moreover, ship designers are questioning the effectiveness of scoops in metering cooling water to match engine horsepower. Scoop drag has been compared unfavorably with circulating pump power consumption. The writer of this paper provides valuable information with which the designer may predict scoop performance. He recognizes the importance of overboard discharge contours. His results challenge the ship designer to derive a design method which will determine optimum scoop contours, then weigh the advantages of scoop versus pump injection.

The wind tunnel tests of models of condenser scoops reported on in this paper were carried out from a particular angle of approach, which was prompted by the following considerations:

It is recognized that the elements of scoops are the same as those of pumps and turbines. Since the characteristics of operation of the latter are a field familiar to the marine engineer, it appeared advisable to attempt to present the characteristics of scoop action in a form similar to that of pump and turbine characteristics.

It was further desired to obtain basic information rather than specific design data, since it was felt that such information might be welcome as an aid in formulating correct engineering judgment. This has the added advantage that the results obtained apply

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equally well to scoops and to any type of pump suction from outboard, or discharge under water. In conformity with the emphasis on fundamental factors the attempt was made to relate measured performance of scoop models to performance values obtained theoretically, in order to point out those instances where calculation might be substituted for empirical data.

While it is recognized that considerations of weight and space requirements and of simplicity of operation are equally important as considerations of energies and efficiencies, the scope of the investigation has been limited to the study of the scoop problem as an energy problem. To this end it was found necessary to obtain drag measurements both for intake and discharge. The experimental methods applied resemble those used by Th. Troller in a similar investigation.[1] It is hoped that the study, although "academic" in its approach, may add some useful facts to the large volume of information [2, 3, 4, 5, 6] already on hand on this subject.

Throughout the paper the following denotations will be used. They apply both to intake scoops and to discharges.

v_o = wind tunnel velocity or ship's speed
Q = volume of flow passing through scoop
A = area of scoop

$$v = \frac{Q}{A} = \text{nominal velocity through scoop}$$

ρ = density of fluid
D = net drag produced by scoop. Negative values of drag indicate that the drag force is directed toward upstream.
p = static pressure

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(1) F. Rokus and Th. Troller, *Tests on Ventilating Openings of Aircraft*, Journal of the Aeronautical Sciences, Vol. 3 (1936), pg. 203.

(2) H. F. Schmidt, *Theoretical and Experimental Study of Condenser Scoops*, JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, Vol. XLII, (1930), pp. 1-38.

(3) H. F. Hanslik, *Condenser Scoops in Marine Installations*, JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, May, 1931.

(4) H. F. Schmidt and O. L. Cox, *Test of a One-Quarter Scale Model Scoop*, JOURNAL OF AMERICAN SOCIETY OF NAVAL ENGINEERS, August, 1931.

(5) H. F. Schmidt, *Some Notes on E. H. P. Calculations and Propeller Characteristics*, JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, November, 1933.

(6) H. F. Schmidt, *A Criterion of Scoop Cavitation*, JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS.

$q = \frac{\rho v^2}{2}$ = velocity pressure

α = angle of scoop with direction of undisturbed flow

Subscript $(_0)$ refers to conditions in the undisturbed flow past the scoop.

Subscripts $(_1)$ and $(_2)$ refer to conditions at the throat of the intake and discharge respectively.

An asterisk (*) is used to denote values pertaining to the ideal scoop.

The quantities listed above are identified further in the schematic drawing of the condenser circulating water system, Figure 1.

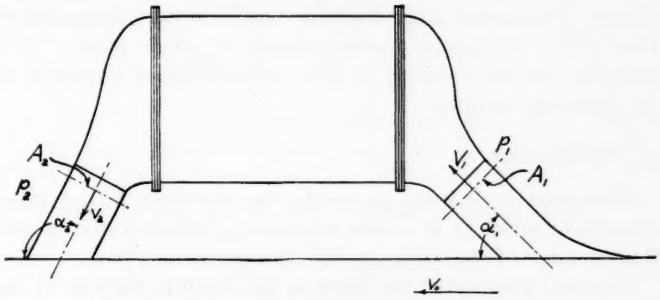


FIGURE 1.—SCHEMATIC SKETCH OF CONDENSER SCOOP.

DIMENSIONLESS QUANTITIES.

The ratio $\frac{v}{v_o} = \frac{\text{nominal velocity in the scoop}}{\text{velocity of undisturbed flow past the scoop}}$ has been adopted as the independent variable against which the quantities representing scoop performance are plotted. It is found to be a sufficient criterion for the correlation of geometrically similar flows if Reynold's number can be neglected. The effect of variation of Reynold's number will be dealt with in connection with the discussion of test results.

Static pressures are presented by coefficients $c_p = \frac{p - p_o}{q_o}$ (1)

which is the ratio

$$\frac{\text{pressure difference across scoop}}{\text{velocity pressure of undisturbed flow past the scoop}}.$$

Finally, drag values are reduced to non-dimensional form by the formulation of a drag coefficient, $c_D = \frac{D}{Aq_o}$ (2)

Performance Characteristics of an Ideal Scoop.

In deriving the performance characteristics of an ideal scoop we assume an ideal fluid. This assumption implies absence of internal friction of the fluid as well as of skin friction. Consequently, a boundary layer does not exist, nor does separation of flow occur. It further implies absence of shock losses. It is assumed that the direction of flow is at all points tangential to the bounding surfaces.

1. Intake scoop.

The scoop is designed to supply the condenser with a given quantity of water, Q, at a static pressure, p_2, sufficient to overcome the resistance of the condenser and the connecting piping.

The total pressure of the water in the scoop is the sum of the static pressure and the velocity pressure, $p_1 + q_1$. The total pressure of the undisturbed flow relative to the hull of the ship is $p_0 + q_0$. Since, according to our assumption, the conversion of a part of the kinetic energy into pressure energy takes place without losses, the total pressure in the scoop is equal to the total pressure of the undisturbed flow.

Consequently $p_1 - p_o = q_o - q_1$ (3)

or, in non-dimensional form, $c_p = 1 - \left(\frac{v_1}{v_o}\right)^2$ (3a)

The drag produced by the scoop can be calculated from the Impulse Theorem. By this Theorem $D = Q\rho v_o$ (4)
or, when substituting $Av_1 = Q$ and introducing the drag coefficient, equation (2),

$$c_D = 2\,\frac{v_1}{v_o} \tag{4a}$$

The required propulsive energy corresponding to this drag is

$$E = Dv_o = 2Qq_o \tag{5}$$

It is seen that, precisely in analogy to the action of a pump, the scoop converts propulsive, *i. e.* mechanical, energy into pressure energy and kinetic energy of the circulating water delivered to the condenser.

The following ratios of output to input may be calculated for the scoop:

$$e_{s_1} = \frac{Q\,(p_1 - p_o)}{Dv_o - Qq_o} \tag{6}$$

or, in non-dimensional form,

$$e_{s_1} = \frac{c_p}{c_D - \frac{v_1}{v_o}}\,\frac{v_1}{v_o} \tag{6a}$$

which takes the place of the static efficiency of pumps, and

$$e_{t_1} = \frac{Q\,(p_1 + q_1 - p_o)}{Dv_o - Qq_o} \tag{7}$$

or, expressed in non-dimensional quantities,

$$e_{t_1} = \frac{c_p + \left(\frac{v_1}{v_o}\right)^2}{c_D - \frac{v_1}{v_o}}\,\frac{v_1}{v_o} \tag{7a}$$

which takes the place of the total efficiency of pumps. The additional kinetic energy, Qq_0, which the circulating water has relative to the absolute system of coordinates has been entered in the denominator, as both input and output are measured relative to the system of coordinates moving with the ship. When substituting the values for c_p and c_D from equations (3a) and (4a) it is seen that the total efficiency of the ideal scoop is unity and the static efficiency

$$e_{s_i} = 1 - \left(\frac{v_1}{v_0}\right)^2 \qquad (8)$$

The drag coefficients for the ideal intake calculated from Eq. (4a) are plotted on Figures 4 to 6.

2. DISCHARGE.

It can be proven by introducing the concept of a source as used in potential flow theory that a jet of fluid discharged into uniform parallel flow of an ideal fluid produces a propulsive force. For the purpose of the present investigations certain conclusions can be drawn relative to the force produced by a discharge from the following reasoning, which although not as rigorous, do not require this special concept. For greater clarity and simplicity, let us consider a cylindrical discharge placed normal to the direction of undisturbed flow, Figure 2. Furthermore, let us neglect the deflection in downstream direction experienced by the jet after it has left the discharge. The jet of water issued from this discharge represents an obstruction to the flow and it may be expected that the pressure distribution around its circumference is similar to that around a solid cylinder exposed to flow at right angles to its axis; namely there will be positive pressure in the surface facing upstream and reduced pressures on the surface facing downstream. These pressures will penetrate into the jet and also extend parallel to its axis upstream a distance inside the discharge. Thus, increased pressures act upon the forward wall of the discharge and reduced pressures upon the rear wall. The combined effect of these pressures is a pressure force directed upstream, *i. e.* a negative drag. The situation, as described above, is not materially changed if the jet is deflected in downstream direction immediately upon leaving the discharge. Figure 2a serves to indicate the streamline pattern and the pressure distribution along the walls of the discharge that may be expected in this case. The negative drag of a jet of fluid discharged at right angles into parallel flow can readily be demonstrated by experiment.[7] In case the

(7) An apparatus demonstrating the negative drag of a jet of fluid discharged at right angles into parallel flow was presented by the author at the Fifth International Congress of Applied Mechanics in Cambridge, in September, 1938.

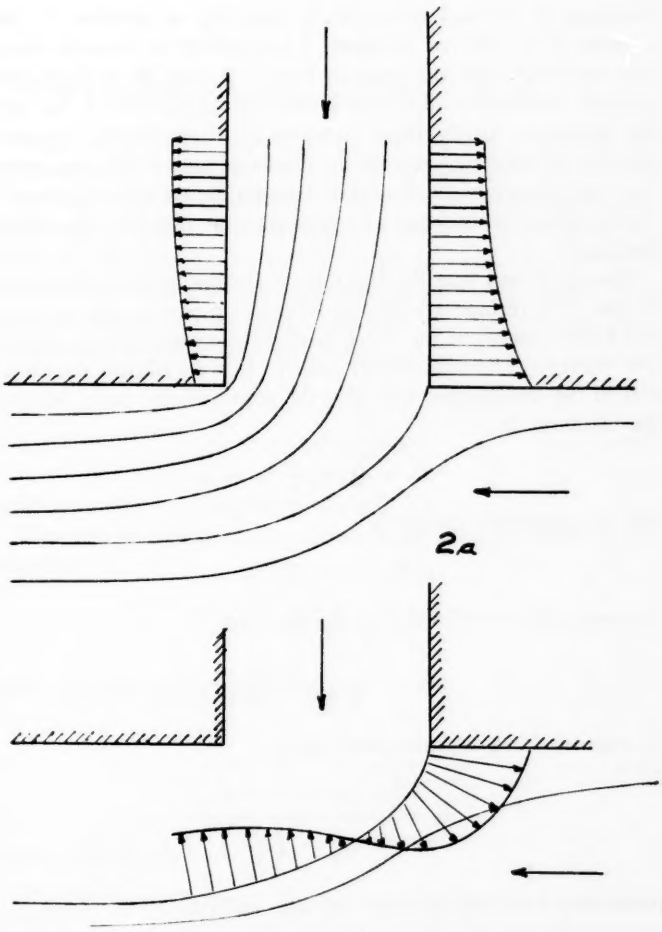


FIGURE 2A.—STREAMLINES AND PRESSURES AT THE DISCHARGE.
2B.—PRESSURES ON THE SURFACE OF THE JET IMMEDIATELY AFTER DISCHARGE.

discharge is inclined downstream, there is, in addition to the negative drag referred to above, a component in forward direction resulting from the reaction force. Figure 2b indicates the pressure distribution along the outline of the jet after it has left the discharge. Partly, these pressures are transmitted to the surface of the plate surrounding the discharge and partly they penetrate upstream into the discharge, thus producing a back pressure. This explains the existence of a pressure resistance, $p_2 - p_0$, at the discharge.

Thus it is seen that the function of the discharge is analogous to that of a turbine, namely, to reconvert a part of the pressure and kinetic energy of the water leaving the condenser into propulsive energy. The total energy relative to a coordinate system at rest in the undisturbed flow past the scoop, of the water leaving the discharge is

$$E_2 = Q\,(p_2 + q_2 + q_o)$$

and the propulsive energy is

$$e_2\,E_2 = (-D_2)\,v_o$$

Consequently, the efficiency of the discharge is

$$e_2 = \frac{(-D_2)\,v_o}{Q\,(p_2 + q_2 + q_o)} \qquad (9)$$

or, expressed in non-dimensional units,

$$e_2 = \frac{(-c_{D_2})}{\left[\, c_{p_2} + \left(\frac{v_2}{v_o}\right)^2 + 1 \,\right] \frac{v_2}{v_o}} \qquad (10)$$

Proceeding from this equation, the ideal efficiency of the discharge can be calculated as follows: For the particular case of discharge at 90 degrees to the direction of flow, assume an ideal fluid, equal Bernoulli's constant for both the fluid discharged and the main body of fluid, and substitute a source for the discharge. The drag coefficient of the discharge then becomes

$$c_{p_2} = -2\,\frac{v_2}{v_o}$$

When assuming $A_2 = A_1$ it follows further that $c_{p_2} = c_{p_1}$

When substituting these values into Eq. (10) it is seen that the efficiency of the 90-degree discharge for an ideal fluid is unity.

In calculating the ideal efficiency of the backwardly sloping discharge the drag is calculated from the reaction of the jet if the pressure difference across the discharge, $p_2 - p_0$, which may be regarded as of the same nature as the pressure drop across a pipe bend, is assumed to be zero. The ideal efficiency of the backwardly sloping discharge then becomes

$$e_2^* = \frac{2\,\frac{v_2}{v_o}\cos\alpha}{1 + (v_2/v_o)^2} \qquad (10a)$$

which was plotted in Figures 9, 10, and 11.

The overall efficiency of a scoop installation is given by the equation

$$e = \frac{Q\,(p_1 - p_2)}{(D_1 + D_2)\,v_o} \qquad (11)$$

or, in non-dimensional quantities,

$$e = \frac{c_{p_1} - c_{p_2}}{c_{D_1} - c_{D_2}\,\frac{A_2}{A_1}}\,\frac{v_1}{v_o} \qquad (11a)$$

WIND TUNNEL TESTS.

The actual performance of condenser scoops was investigated by tests of a number of scale models of typical intake scoops and discharges conducted in the wind tunnel of Case School of Applied Science. The test set-up is shown in Figure 3, which shows essential details and serves to explain their function.

The models tested are listed in Tabulation I.

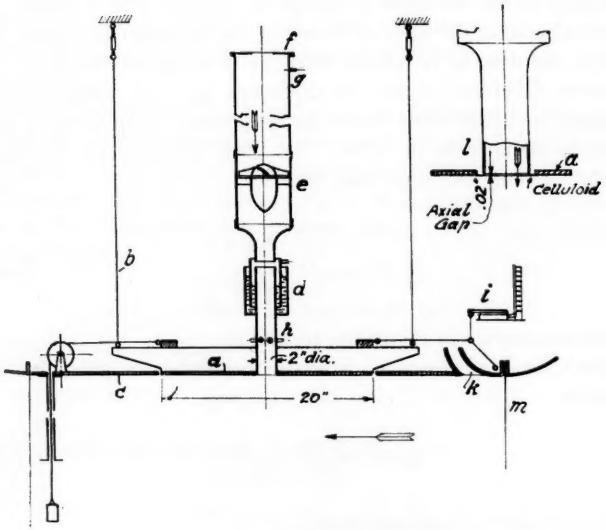


FIGURE 3.—TEST SETUP.

a. Floating plate, 14" by 20".
b. Suspension wires.
c. Ceiling of working section.
d. Water seal.
e. Fan.
f. Sharp edged orifice.
g, h. Pressure taps.
i. Hydrostatic scale.
k. Slots for boundary layer control.
l. Arrangement for measurement of friction drag only.

TABLE I. MODELS OF INTAKES AND DISCHARGES TESTED.

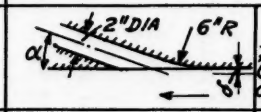
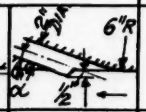
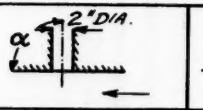
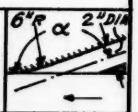
TYPE	INTAKE			DISCHARGE				
DIMENSIONS								
DESCRIPTION	FLUSH		WITH LIP	FLUSH		FLUSH	FLUSH	FLUSH
ANGLE α	20°	20°	20°	90°	90°	120°	135°	160°
BOUNDARY LAYER THICKNESS	1"	1/4"	1"	1"	1/4"	1"	1"	1"

TABLE I.

MEASUREMENTS.

Conditions of operation were varied by varying the wind tunnel speed and the quantity of flow through the scoop. Reynold's numbers varied between Re = 58,500 and 16,000, where Reynold's number is based upon the velocity through the scoop and the diameter of the scoop.

The following measurements were taken:

(1) Wind tunnel speed,
(2) Quantity of flow through scoop by means of orifice measurement,
(3) Static pressures at 6 pressure connections distributed equally around the circumference of the scoop in a transverse plane five diameters away from the intersections of its axis with the surface of the plate,
(4) Drag of plate and scoop combined.

In addition:

(5) Boundary layer traverses were taken at various locations on the plate.

The drag of the flat plate alone without an opening for the scoop was determined and its value deducted from the readings to obtain the net drag, D.

The results were calculated and presented in Figures 4 to 11 in non-dimensional form by plotting the coefficients c_p and c_D given by equations (1) and (2), respectively, against the ratio of velocities $\frac{v}{v_o}$.

The efficiencies e_{s_1}, e_{t_1} and e_2 used in the presentation of the test data are calculated from equations (6a), (7a), and (9), respectively.

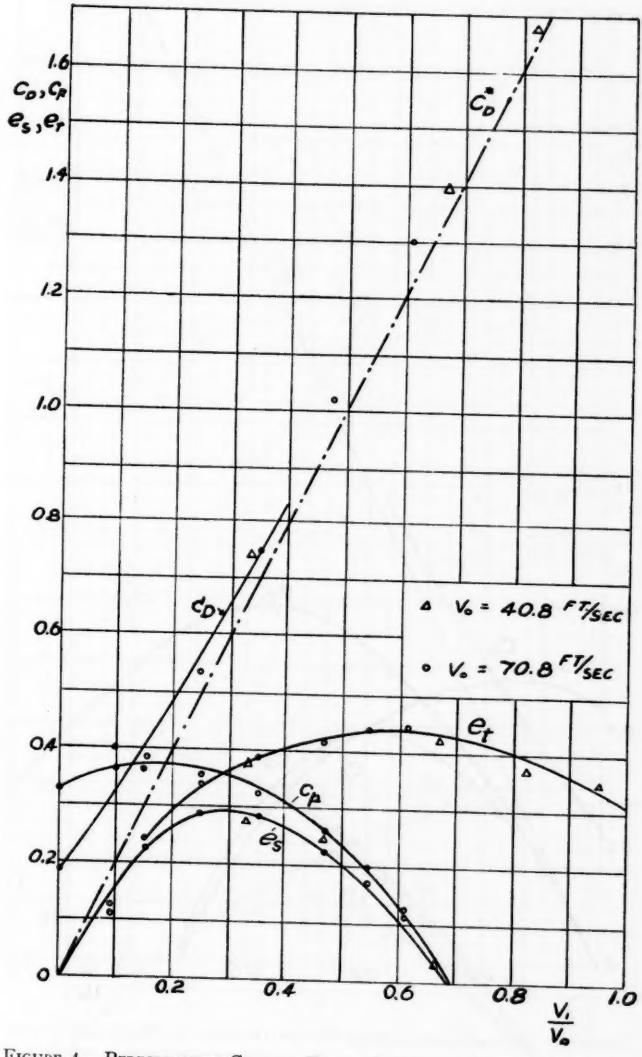


FIGURE 4.—PERFORMANCE CURVES, FLUSH INTAKE, 1" BOUNDARY LAYER.

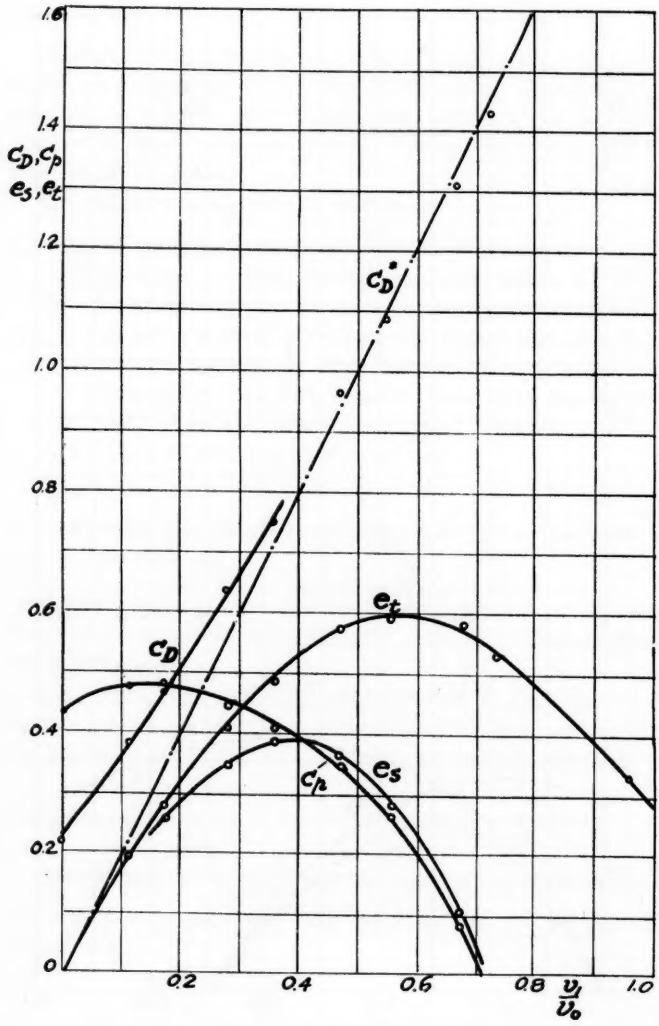


FIGURE 5.—PERFORMANCE CURVES, FLUSH INTAKE, ¼" BOUNDARY LAYER.

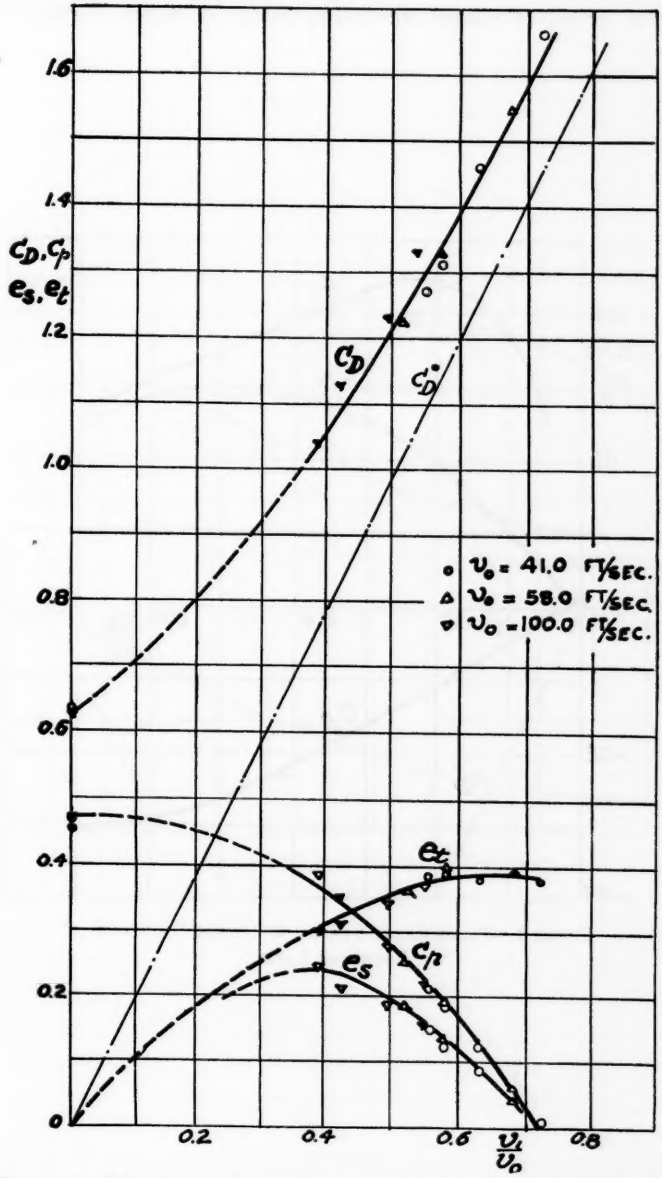


FIGURE 6.—PERFORMANCE CURVES, INTAKE WITH LIP, 1" BOUNDARY LAYER.

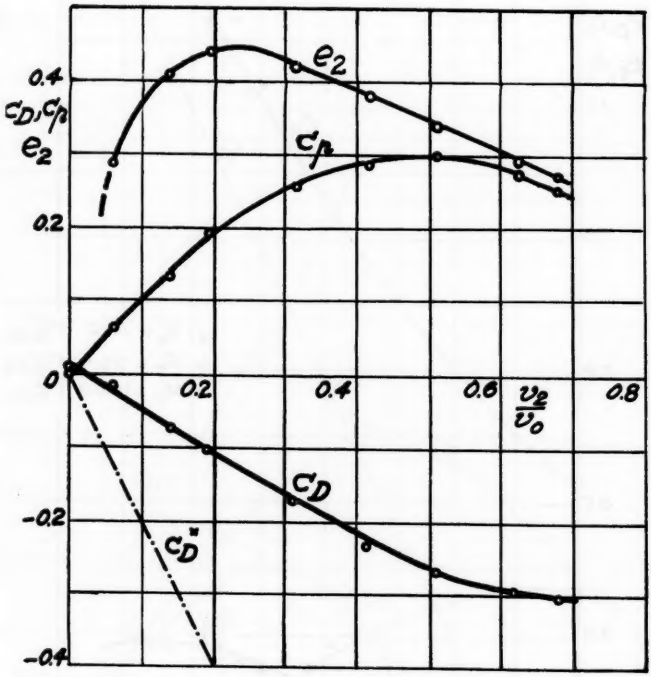


FIGURE 7.—PERFORMANCE CURVES, 90 DEGREE DISCHARGE, 1" BOUNDARY LAYER.

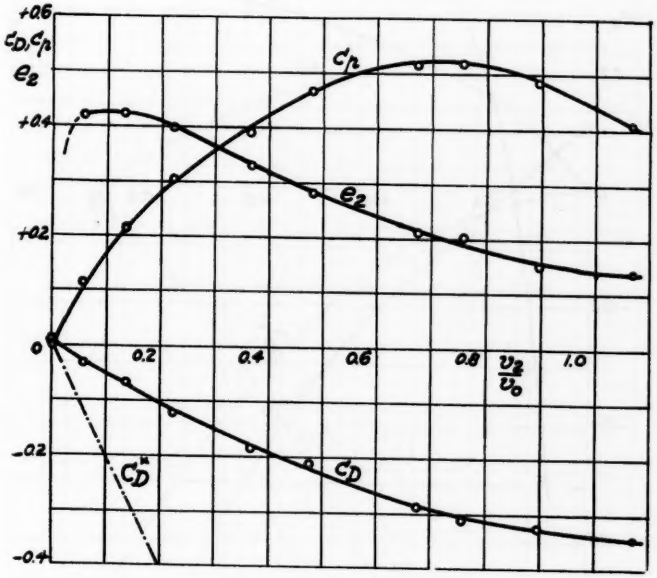


FIGURE 8.—PERFORMANCE CURVES, 90 DEGREE DISCHARGE, 1" BOUNDARY LAYER.

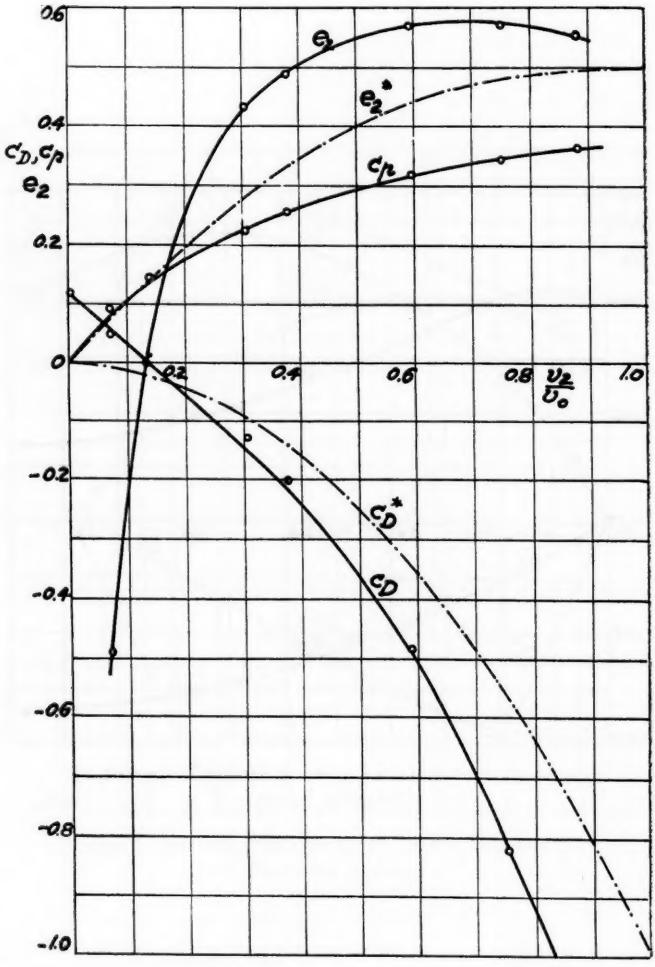


FIGURE 9.—PERFORMANCE CURVES, 120 DEGREE DISCHARGE, 1" BOUNDARY LAYER.

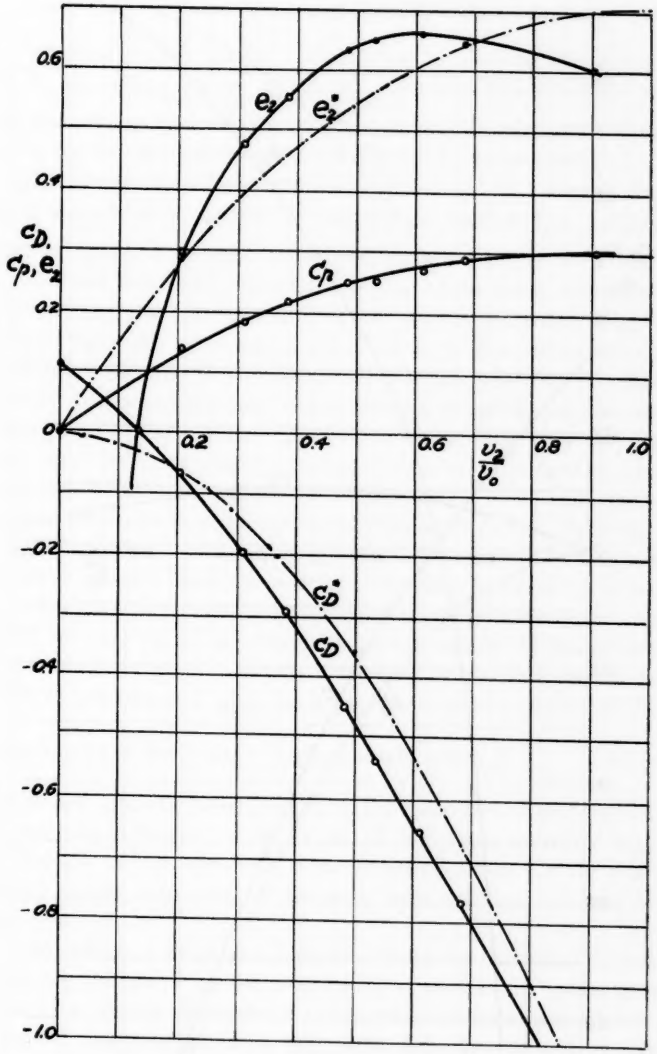


FIGURE 10.—PERFORMANCE CURVES, 135 DEGREE DISCHARGE, 1" BOUNDARY LAYER.

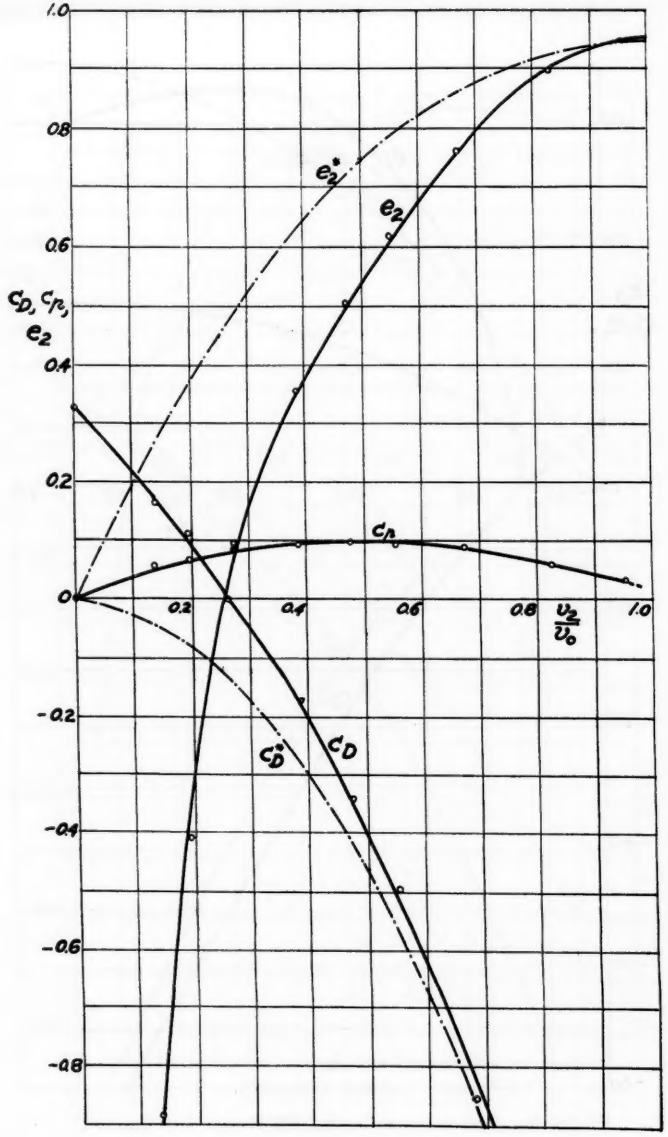


FIGURE 11.—PERFORMANCE CURVES, 160 DEGREE DISCHARGE, 1" BOUNDARY LAYER.

Discussion of Results.

(*a*) Analysis of Losses. In addition to showing the curves of c_p, c_D, and e_{s_1} and e_{t_1} calculated from test measurements of the flush scoop, model B, Figure 5 also shows the calculated values of c_D for the ideal scoop, which are denoted by an asterisk.

The discrepancy between measured and calculated values of the inlet scoop is most marked for the pressure coefficient, c_{p_1}. This may be traced to a number of factors, such as friction on the surfaces, shock losses at the downstream edge of the scoop, flow separation along the upstream wall of the scoop. Moreover, a pronounced secondary flow was noted in the form of a pair of vortex filaments extending into the scoop. The losses caused by this secondary flow are of the same nature as those caused by the induced drag of an airplane wing. Calculations indicate that they may be decreased by increasing the width of the scoop normal to the direction of flow and decreasing its dimensions in up and downstream direction, thus increasing the "aspect ratio" of the scoop.

The increase of measured drag over theoretical may be ascribed to three causes. First, the velocity at the inlet to the scoop is not constant, which results in an increase of the momentum of the fluid entering the scoop. Secondly, in the case of the scoop with lip, it may be traced to suction at the back of the lip occurring at certain conditions of operation. Finally, it will be noted that the discrepancy is particularly large at small values of $\frac{V}{V_o}$. This is attributed to the turbulence set up by the scoop and by exchange of momentum at the inlet to the scoop. On the whole, measured drag values are in fair agreement with theoretical values for the flush scoop so that calculation of the drag from equation (4) may be recommended.

(*b*) Effect of Reynold's Number. Since the individual factors affecting the action of the scoop, such as transfer of momentum and skin friction, are related to Reynold's Number in different ways it might be expected that some difference of test results obtained at the same $\frac{V_1}{V_o}$, but at different Reynold's Number,

should appear. For this reason, the wind tunnel speeds at which the test points were obtained, have been indicated in Figures 4 and 6. From these figures it is seen, however, that within the range of Reynold's Numbers covered by the model tests the spread of values produced by scale effect is so small as to lie within the limits of accuracy of the measurements.

(*c*) Effect of Lip. Comparative chararteristics of a scoop with, and without, a lip were obtained for the same boundary layer thickness, Figures 4 and 6, respectively. In comparing the corresponding curves it is seen that at low $\frac{v_1}{v_o}$ values the scoop with lip produces higher pressures than that without lip. At higher $\frac{v_1}{v_o}$ values, however, the pressures produced by the flush scoop exceed those of the scoop with a lip. The comparative tests further show that the efficiency of the flush scoop is materially higher than that of the scoop with a lip throughout the entire range investigated.

(*d*) Range of $\frac{v_1}{v_o}$ for Maximum Efficiencies. Maximum static efficiencies of scoops occur at $\frac{v_1}{v_o}$ values between .3 and .4. This coincides with the range of rated capacity of full-scale scoop installation. It is believed that the peak of static efficiencies can be moved to higher $\frac{v_1}{v_o}$ values by combining intake scoops with effective diffusers, as recommended by F. H. Schmidt.[8] Maximum total efficiencies for intake scoops occur in the neighborhood of $\frac{v_1}{v_o} = 0.6$. It appears that this range should advantageously be chosen for pump intakes.

(8) loc. cit.

(*e*) Effect of Boundary Layer Thickness. The comparative wind tunnel tests of the flush intake scoop with a boundary layer thickness of 1 inch and ¼ inch, respectively, give evidence that the static pressure produced by the scoop increases as the boundary layer thickness decreases. Since a corresponding increase of the drag does not take place, the efficiency likewise increases with decrease of boundary layer thickness.

(*f*) Angle of Discharge. The tests of discharges at various angles of inclination with respect to the direction of the undisturbed flow corroborate the known fact that considerable improvement, both in regard to back pressure at the outlet and to efficiency, can be obtained by sloping the discharge downstream. Measured drags and efficiencies for the discharges are considerably smaller than the ideal values calculated on the assumption of a point source, see Figures 7 and 8, but larger than the ideal values calculated from the reaction force, Eq. (10a), except for the 160 degree discharge, Figure 11.

Maximum efficiencies have a tendency to occur at higher values as the slope of the discharge is increased. This fact suggests the idea that for maximum efficiency of the discharge, the slope should be chosen according to the value of the $\frac{v_2}{v_0}$ ratio.

Figure 9 serves to point out the possibility of decreasing the back pressure and of increasing the efficiency of the discharge to nearly 100 per cent by fairing the outlet and by choosing a very large angle of slope.

A SHORT HISTORY OF THE NAVAL USE OF FUEL OIL.

PART V.

By Lieutenant Commander James E. Hamilton, U. S. Navy, Member.*

There is a popular tendency to regard fuel oil as a by-product left over after all special components have been removed from the crude. In the early nineteen-twenties such oil might have been acceptable with, perhaps, a modicum of blending. Thereafter, the increased use of petroleum products stimulated production techniques to obtain a greater yield of lighter grades. Fuel oil as a by-product became inferior.

The author in this part of his history covers the period from 1920 to 1934 under the subheads "Quality" and "Application." He discusses the post-war efforts to maintain good quality fuel oil. In spite of obstacles, these efforts combined with commercial impulses to encourage technical studies. The technique of processing petroleum improved at an accelerating rate. In the future we may find that "by-products" no longer exist among the component parts of crude oil.

QUALITY.

In Part III, the birth of the various specification grades of fuel oil was described. This occurred under the aegis of the "Committee on Standardization of Petroleum Specifications" which acted under the U. S. Fuel Administration.

The war specification was an admirable thing. It did its share toward winning the war. The deplorable fact is that it, or its sponsors, led to a perpetuation of a system which stultified the advancement of fuel oil knowledge to the temporary disadvantage of the Navy and the National Defense.

* Budget Officer, Bureau of Engineering, Navy Department, Washington, D. C.

During a war for which a nation has not been prepared, many expedients must be adopted. Such was the fuel oil specification which took care of the difficulties which arose under war conditions where the requirements of practically all shipping in operation, either naval or commercial, was of vital importance to the United States. The specifications were only a part of the cure since there were also, allocations, truly patriotic desire to help by the oil industry, and practically 100 per cent control of all fuel oil markets in a single agency—the United States Government. The specification's genesis should have been borne in mind, and steps taken as soon after the end of the war as possible to make an adequate study of the situation and to prepare the specification which the Navy needed in order that it might be prepared for the next emergency. Loss of control by the Navy prevented this.

The "Committee on Standardization" was the first Federal body with authority to prepare and issue purchase specifications which would be binding on all departments of the government. This committee when organized was given a life which would expire six months after the end of the war. Its last revision of the fuel oil specifications, however, did not become effective until December 29, 1920.

The successor to the wartime committee was the "Interdepartmental Committee on Standardization of Petroleum Specifications" which on October 10, 1921, became the "Interdepartmental Petroleum Specification Committee." Commander (now Captain) H. A. Stuart, U. S. N., represented the Navy as a member of these committees. In March, 1922, the Interdepartmental Committee issued its Specifications for Petroleum Products as Technical Paper 305 of the U. S. Bureau of Mines.

Not long after its establishment, the Interdepartmental committee became a subcommittee of the Federal Specifications Board. The Board's first specification was issued on October 31, 1922, and is still under the same board, although it has been revised several times.

The originators of the Federal Specifications Board held the belief that efficiency of the federal government demanded that there be strict standardization in the specifications used by all federal agencies for any purpose. The Navy's insistence that it alone was competent to prepare specifications for materials which could be

considered as having a strictly military application or effect, resulted in a ruling that for such materials the Navy did not have to use the Federal Specifications. There has been constant pressure to force the Navy completely into the hands of the Board but, in form at least, independence has been maintained.

The Navy's first specification for fuel oil, as a separate thing from a requisition or purchase order, was issued on June 1, 1921. This infant was the identical twin of the then existing issue of the Committee's specification. It was redressed by calling it a Navy Department Specification, numbered 7-0-1.

Specification 7-0-1 was revised 4 times, the last being on June 1, 1933, without making any substantial change in it. There were four grades of fuel oil specified, in 1921. They were "Fuel Oil (Navy Standard)", and Bunker Fuel Oils, A, B, and C. In the 1933 revision Navy Standard Fuel Oil was redesignated as Bunker D. The characteristics covered by the specifications in its different revisions are shown in the following table.

		REVISION DATED.				
		6/1/21	5/1/23	3/2/25	3/1/28	6/1/33
Flash Point Lower limit.	Bunker A	150 *	150 *	150 *	150 *	150
	Bunker B	150	150	150	150	150
	Bunker C	150	150	150	150	150
	Bunker D (Navy Std.)	150 *	150 *	150 *	150 *	150
Viscosity. Upper Limit	Bunker A	140SSF at 70°	100SSF at 77°	Same	Same	Same
	Bunker B	100SSF at 122°	100SSF at 122°	do.	do.	do.
	Bunker C	350SSF at 122°	300SSF at 122°	do.	do.	do.
	Bunker D	140SSF at 70°	100SSF at 77°	do.	do.	do.

* If viscosity is greater than 30SSF at 150° F., flash point shall not be below temperature at which viscosity is 30.

		6/1/21	5/1/23	3/2/25	3/1/28	6/1/33
Water and Sediment. Upper limit	Bunker A	1.0%	1.0%	1.0%	1.0%	1.0%
	Bunker B	1.0%	1.0%	1.0%	1.0%	1.0%
	Bunker C	1.0%	1.0% *	1.0% *	2.0% †	1.0%*
	Bunker D	1.0%	1.0%	1.0%	1.0%	1.0%

The only other special requirement was in the case of Navy Standard Fuel Oil (Bunker D) where a low limit of 1.5 per cent sulfur was specified in all of the revisions.

All five issues required that the fuel oil of whatever grade should be a "hydrocarbon oil, free from grit, acid, and fibrous and other foreign matter." All but the 1933 revision required that the fuel oil should be strained.

As previously stated, the 1921 Navy specification was essentially the same as the first one issued in 1918. There was no change in the entire fifteen year period as regards flash point until 1933 when the higher flash point for oils whose viscosity at 150 degrees F. was greater than 30 SSF was removed. Not until 1933 was it realized that this 1918 requirement had become unnecessary in 1921. The requirement was originally specified because the Navy used only "Navy Standard" or "Bunker A" in its combatant ships and would not permit oil to be heated above the flash point. At the same time it was required that fuel oil be heated to give it its optimum atomization viscosity which until 1921 was thought to be 150 SSU. In 1921 it was determined that the optimum atomizing viscosity was between 50 and 80 SSU and, since a higher temperature was necessary to accomplish this, it was permitted to heat the oil above its flash point between the heaters and the burners. It was forbidden to heat within 20 degrees of the fire point, yet this point was not limited by specification and the original flash point was not dropped for 12 years.

Only two changes were made in the viscosity requirement, both in 1923. To meet commercial practice it was desirable to change the temperatures at which viscosities were measured to 77 and 122 degrees F. These temperatures, equivalent to 25 and 50 degrees C.

* 1.0% water plus 0.25% sediment.
† 2.0% water and sediment but sediment not to exceed 0.25%.

had been brought in with the first viscosimeters introduced from Europe. To change the measuring temperature from 70 to 77 without changing the actual intent of the specification, it was necessary to change the viscosity. 100 SSF at 77 degrees F. corresponds very closely to 140 SSF at 70 degrees F. so the change in the specification had no effect on the quality of the oil obtained, merely on the test requirements. The other viscosity change was the drop in the upper limit for Bunker C from 350 to 300 SSF. The Navy at the time was expecting to alter fuel oil equipment so that it could burn Bunker C, but believed that the upper limit to which it would be able to go was 300 SSF.

The water and sediment requirement was unchanged throughout the fifteen years except as regards Bunker C. As stated above, the Navy in 1923 expected to shift its purchases from the higher grades to Bunker C. The centrifuge method of test which was specified for measuring water and sediment was not trusted for more viscous oils so the two were separated and more exacting tests required. Water was measured by distillation, a standard method, and sediment by extraction, a Navy method not standardized by the industry. This specification change was concurrent with the plan to install fuel oil separators in vessels discussed under "Utilization." Both were based on a misconception of what the specification for Bunker C Fuel Oil covered.

The requirement that the oil be strained was removed in 1933 when it was determined that there had been little compliance with the requirement because most suppliers of fuel oil had no strainer installations and would not install them. It was a case of either getting no oil or waiving the requirement so it was deleted.

During the period the wartime specifications were in use by the Navy, it devoted little time to questions of specification requirement. The nature of the few changes which were made indicate this conclusively. From 1921 until about 1928 the Bureau of Engineering, in the interest of economy, devoted a great deal of thought to how it could use lower and hence cheaper grades of fuel oil. After the war the Navy was using Bunker A fuel oil on the East coast where practically all of its supply was obtained. When the Pacific fleet, containing a large number of oil burners, was organized in 1921, it was discovered that West Coast suppliers

would not or could not furnish a Bunker A. Bunker B was specified and used on the West Coast with no difficulty. There was some hesitancy in going to Bunker B on the East coast because there appeared to be a plentiful supply of Bunker A which assured much easier operations and the difference in price between A and B was not very great. However, the difference in price between A and C was quite appreciable and a shift to the cheaper oil would have meant a saving.

The desired change from Bunker A to C was responsible for a great deal of test running afloat and at the Fuel Oil Test Plant (now Boiler Laboratory) to determine the practicability of the shift. Nothing definite was determined and the plan was relegated to the background when the publicity over the Naval Petroleum Reserves arose. It might have disappeared altogether had not the demands of that grand old year 1929, on the petroleum industry been so great that Bunker A fuel oil began to grow quite scarce. The Navy began to worry about whether it could buy Bunker A much longer at any price and even a little bit as to whether or not it would be able to obtain any satisfactory fuel oil.

The 1929 situation revived the shipboard tests on the use of the cheaper grades of fuel oil. It also resulted in Lieutenant Commander W. H. Osgood, U. S. N., long identified with oil through his connections with the receivership of the Teapot Dome reserve, being ordered to visit certain refineries and to study the question of the supply of fuel oil. Osgood determined that "Quality" was the essence of the answer to the "supply" question. His report recommended a considerable amount of research work on fuel oils. As a result he was ordered to the Naval Research Laboratory to take charge of the investigation. Dr. Parry Borgstrom was added to the staff of the laboratory as Osgood's technical assistant.

Osgood assembled a representative set of fuel oil samples, set up the necessary equipment, and laid out a research program. He was then detached to the hospital and subsequently retired. The work laid out proceeded along research lines under Dr. Borgstrom.

At about this time the difficulties which were mentioned under "Utilization" began to appear in the fleet. Oil which fulfilled the specifications completely was proving to be entirely unsatisfactory. It was necessary to do something immediately without

waiting for the results of research. Only one type of fuel oil then being delivered caused the great difficulty and when the supplier of that oil stated that oil of the type could not be produced to have a specific gravity of less than 0.95, that specific gravity was added as a requirement of the specification, *entirely to exclude the one type of oil* and not because specific gravity had any value *per se* in the specification.

It appeared that "Quality" was decidedly a factor in the supply question. It appeared further that quality had caught up with the Navy before it was ready to handle it. No one else was in any better condition. The petroleum industry had always taken Bunker Fuel Oil as a matter of course. It was usually easy to sell and had required no real research or investigation. There was considerable theory but no experimental data on which to write a specification which would both protect the Navy against deliveries of unsatisfactory oil and would also be sufficiently unrestrictive so that some dealers in fuel oil would offer to supply it to the Navy under those specifications.

The Fuel Oil desk in the Bureau of Engineering had been done away with at the time that the control of the Naval Petroleum Reserves was transferred to the Secretary's Office. All questions concerning fuel oil were assigned to the Specifications Desk in the Design Division, along with the specifications of all other engineering materials used by the Navy. When the heater difficulty started and Osgood was retired, it became apparent that it would be absolutely necessary to establish some agency for handling fuel oil alone, later to take over, in addition, all petroleum products.

The fuel oil desk was re-established in the summer of 1932 and shortly thereafter the Navy Regulations were changed to make the responsibility for fuel oil specifications, the Bureau of Engineering's. Previously the Bureau had been charged only with the inspection of fuel.

Under its now specific authority, it became incumbent on the Bureau to undertake the preparation of a specification for fuel oil which would meet two general conditions. It must be entirely satisfactory as a "fighting fuel" for men-of-war, and it must be obtainable on the market at a reasonable price. Manifestly, with no basic information to go on, it was impossible to write the speci-

fication immediately. It was decided to continue the 0.95 specific gravity requirement through the fiscal year 1934 with the definite goal of having the new specification ready for use in time for the schedule for 1935 fuel oil.

Osgood's Naval Research Laboratory set-up provided for chemical research on a number of samples of typical fuel oils. It provided no means of correlating this research with service suitability. There appeared to be two definite questions to be correlated with basic theory. One was the action of fuel oil in heaters, and the other its actions in burning equipment.

Because of need for haste, it was decided that the chemical part of the investigation would be continued at the Research Laboratory. A rapid survey of the field indicated that the heater problem could best be undertaken at the Engineering Experiment Station at Annapolis, Md., because most such work which had been done previously had been conducted there. Similarly, it was inevitable that the burning problem should be turned over to the Naval Boiler Laboratory which not only had the necessary equipment but was probably staffed with as expert and experienced fuel oil burning engineers as could be found in the world.

In order to correlate the work of the three laboratories, it was essential that all three work on identically the same oil. Every oil company in the country which had a refinery large enough and properly located to be a factor in the supply of fuel oil to the Navy, was given opportunity to sell sufficiently large samples of fuel oil to the Navy. These samples were required to meet certain physical specifications only. It was hoped that enough of them could be obtained to provide a range of suitability in burning and heating characteristics so that the suitability could be correlated with determinable chemical and physical characteristics developed at the Research Laboratory.

In all, 18 carload samples were obtained from refineries on all three coasts. A barrel of the oil was taken from the tank car and sent to the Research Laboratory and the remainder divided about equally between the Naval Boiler Laboratory and the Engineering Experiment Station. Thus was the uniformity of the material on which the three laboratories were working assured. The Boiler Laboratory ran a critically observed combustion test of each oil

using a small size but conventional type boiler. The Experiment Station, using a test set-up of heater tubes, ran the oil through these tubes at different temperatures and rates of flow.

While the tests were underway, pending determination of the necessary information, the following skeleton specifications were analytically prepared as a groundwork for use as soon as the data became available. The notes which follow the specification explain what was aimed at.

OIL, FUEL, NAVY.

A. Applicable Specifications.
A-1. General Specifications for Inspection of Material, issued by the Navy Department, together with Federal Specification VV-L-791, in effect at the date of opening bids, shall form a part of these specifications.

B. Grades.
B-1. Navy fuel oil shall be of but one grade.
Note: Other grades of fuel oil are covered by specifications 7-0-1 and 7-0-2.

C. Material and Workmanship, etc.
C-1. Navy fuel oil shall be a hydrocarbon oil.

D. General Requirements.
D-1. See Section E.

E. Detail Requirements.
E-1. Navy fuel oil shall conform to the following requirements:

E-1a. It shall be free from grit.
E-1b. It shall be free from acid.
E-1c. It shall be free from fibrous or other foreign matters likely to clog or injure the burners or valves.
E-1d. The specific Gravity shall be not greater than (1) (1′) degrees A. P. I.
E-1e. The flash point shall not be lower than (2) degrees F. when tested in a Pennsky-Martens closed tester.

E-1f. The viscosity shall be measured at two points as follows:

E-1f-1. The viscosity in Saybolt Furol seconds shall be not greater than (3) seconds at (4) degrees F.

E-1f-2. The viscosity in Saybolt Universal seconds shall be not greater than (5) seconds at (6) degrees F.

E-1g. The sludge effect at (7) degrees F. shall be not greater than (8).

E-1h. The oil as delivered shall not contain more than (9) per cent of total water.

E-1i. Ash shall not be greater than (10) per cent.

F. Methods of Sampling, Inspection, and Tests.

F-1. Samples for all tests shall be taken by one of the methods described in Part 1 of Federal Specification VV-L-791.

F-7. The tests required by paragraph E-1 shall be made by the following Methods:

F-7a. Grit—(A).
F-7b. Acid—(B).
F-7c. Foreign Clogging impurities—(C).
F-7d. Specific gravity—(D).
F-7e. Flash point—(E).
F-7f. Viscosity SSU at (6) degrees F.—(F).
F-7g. Viscosity SSF at (4) degrees F.—(G).
F-7h. Sludge effect—(H).
F-7i. Ash—(I).

G. Packaging, Packing and Marking for Shipment.

G-1 Fuel oil shall be delivered in the manner required by the terms of the contract or order. If delivery is made in containers each container shall be marked "Navy fuel oil," quantity contained, contract or order number, and the name of the contractor.

G-2. Each container, 55-gallon capacity, used for shipments or storage of fuel oil, shall be in accordance with Navy Department Specifications 42C14 or Interstate Commerce Commission Specification No. 5. The container shall be

clearly stencilled with a durable black paint on both heads, in capital letters at least 1 inch in height, as follows: USE THIS CONTAINER FOR FUEL OIL ONLY.

H. Notes.

H-1. Navy fuel oil is the grade of fuel oil which is used by the Navy for combatant ships of all classes. It is intended for use in a system which is characterized by limited tank heating facilities, complicated piping systems, variable loads, and mechanical pressure atomization.

H-2. Copies of Navy Department specifications and any other specifications forming a part thereof may be obtained upon application to the Bureau of Supplies and Accounts, Navy Department, Washington, D. C. When requesting, refer to specifications by both title and number.

The fuel oil desk of the Bureau prepared the following notes to accompany the above quoted skeleton specifications:

"Under Section E, Detail Requirements, all of the quantitative limits are indicated but not stated. The values which are to appear in the finished specifications are to be determined as follows:

(1) Specific gravity. The limit is to be determined by the Bureau. The purpose of the requirement is to insure ready gravitational separation of oil and water. It is believed that a specific gravity as high as .980 can be permitted. This will allow a minimum differential of about .05 between oil and sea water. Omission of a gravity requirement would very probably widen the available supply and decrease the price but I question that we can handle oils of approximately the same or greater weight than water. If provisions are made for heating any oil-water mixture before separation and for adding some heavy saline solution which is soluble in water (sea or fresh) but not in oil, we can eliminate the gravity requirement and accept the heaviest oils which may be offered. It is suggested that the gravity requirement be inserted originally with the view to its removal in a future revision after the question has been thoroughly studied.

(1′) The A. P. I. gravity should be given as a convenience to suppliers and others who are accustomed to think of gravity in A. P. I. degrees. The figure will be the A. P. I. equivalent of (1).

(2) I believe that the present flash point of 150 degrees F. will be entirely satisfactory. It is low enough to cause no difficulty to refiners and sufficiently high for Naval safety. The figure was originally set as a result of a very thorough investigation by the Flash Point Board in 1914. I know of no new factors which have entered since that time.

(3) The viscosity, Furol seconds, at the higher temperature is that which will permit pumps to deliver full power fuel. Present General Specifications for Machinery require that pumps deliver full load with oil at 700 seconds. The Shipping Board's figure is 375 seconds which is probably much closer to what can actually be handled by the present equipment. The higher the figure, the less restriction will be placed on supply. The viscosity (5) will determine (3) for each oil but not for all oils and the fact that there is such a wide variation in the slope of the viscosity-temperature curves, requires that (3) be specified. Since this viscosity limit is also governed by strainer design and location and by pipe resistances, it should be placed fairly low until a thorough investigation shows definitely what can be handled. For a start a figure of 175-200 SSF is suggested.

(4) This temperature is the maximum which can be reached by the oil at the booster pump. It is the maximum permissible storage tank temperature minus the temperature drop to be expected between the tank and the pump. An investigation in 1931 indicated that a temperature of 120 degrees F. in the tanks was not objectionable to any of the interested Bureaus. G. S. M. requires that tank heating equipment be capable of heating to 150 degrees F. However, it is probable that many ships in service cannot reach much over 80 degrees when operating in cold

water. Assuming a temperature drop of 10 degrees in the lines, (4) should be started at about 70 degrees F. If all ships are eventually equipped for tank heating to 120 degrees F., this temperature would be increased to 110 degrees F. which is probably the upper limit.

(5) This viscosity is the atomizing viscosity which is between 75 and 150 seconds Saybolt Universal. The limit selected for the specifications could very probably be the upper limit, 150 SSU.

(6) This temperature eventually is to be the maximum which is to be permitted for heater discharge minus the temperature drop from heater to burner. If all ships are to have heaters located in each fireroom, the drop can probably be neglected. The temperature to be eventually reached can probably be 200 degrees F. For the present the limit must be placed at the maximum attainable by all ships when heating full power fuel, probably some place between 150 and 175 degrees F.

(7) This has tentatively been inserted as a number or letter. The test for determining this characteristic is to be evolved by the new committee as its first job. It is suggested that the sludging characteristic be designated according to an arbitrary scale for convenience. No information at all is available on this point at the present time.

(8) The temperature at which the sludge formation is to be limited should be the highest to which the oil is heated. With present heaters where flow is undoubtedly streamline up to nearly full power in the first passes, this temperature probably approaches that of the steam, possibly reaching 400 degrees F. If all ships are equipped with a heating system which will permit turbulent flow at all rates of flow (8) should be the same as (6).

(9) Present specifications limit water and sediment combined to 1 per cent. The two should be separately specified. The limit on water can safely go quite high. If the water is free and readily separated, it merely reduces the

amount of *fuel* which can be bunkered. If the water is in emulsion and cannot be separated, it will in addition reduce the boiler efficiency. Steaming radius is the only consideration. 1 per cent for total water should be a safe figure which will place practically no restrictions on the price or supply.

(10) By ash is meant the percentage of noncombustible impurities except water. In practice the figure is very low and can probably be specified as low as .05 per cent and surely no higher than .2 per cent without imposing any hardship on refiners. If the requirement that the oil be free from grit and fibrous matter is met, ash as high as .2 per cent can be permitted without any danger.

Section F. Paragraph F-7.

This paragraph will either contain detailed methods of test or reference to the methods which will be printed in a separate publication as at present. The Federal Specifications Board is to issue VV-L-791, a specification containing the present methods of test for petroleum products. This specification will not, at first at any rate, contain all of the tests which we will need. This should be taken care of by reissuing Appendix VI of the General Specifications for Materials but such is not contemplated. It is intended that VV-L-791 shall be used as such by the Navy. The tests which will have to be included in full in 7-0-3 are (A), (B), (C), and (H).

(A) Absence of grit has always been required but no means has ever been specified for determining it. It is suggested that some very simple test such as rubbing between thumb and finger, between a finger and a glass plate, or between two glass plates will suffice and can be specified.

(B) Tests for acidity are available and can be specified.

(C) Same as (A) at present. Can be specified by requiring that oil being delivered be passed through strainers of a specified design and under specified temperature conditions.

(D) Present standard method using hydrometers to be specified.
(E) Present standardized method of using Pennsky-Martens closed tester to be specified.
(F) Present method of using Saybolt Furol Viscosimeter to be specified.
(G) Present method of using Saybolt Universal Viscosimeter to be specified.
(H) Entirely unknown at present. Must be evolved.
(I) Present method of determination to be specified until a more accurate method is devised.

The only radically new item in the proposed specifications was the "sludge effect" requirement. This term which was chosen originally to describe the tendency to form deposits in fuel oil heaters is not particularly descriptive. In the absence of knowledge as to what characteristic of fuel oil caused heater fouling, the term was arbitrarily used in the initial draft in order that the specifications would include coverage for this previously unspecified bad characteristic.

The new committee which was mentioned in the notes above was brought into existence in the following way. Dr. Borgstrom suggested that an attempt be made to interest the petroleum industry in the Navy's problem. On his suggestion, Dr. T. G. Delbridge of the Atlantic Refining Co. and one of the most active members of Committee D-2 of the American Society for Testing Materials, was invited to a conference in the Bureau of Engineering. This conference was held on 9 February, 1933, and was attended by Dr. R. P. Anderson, an official of the American Petroleum Institute and Dr. K. G. Mackenzie of the Texas Co., as well as by Dr. Delbridge. All three were prominent in Committee D-2 of the A. S. T. M.

The outcome of this conference was the formation of the United States Navy Fuel Oil Committee. The chairmanship of the committee was to be placed in the Bureau of Engineering. The officer who held the fuel oil desk was originally designated as chairman and the other members were among the leading petroleum chemists in the country. Membership was offered to a number of such men and was accepted by the following:

Dr. E. W. Dean, Standard Oil Development Co.
Dr. R. T. Goodwin, Shell Petroleum Co.
Dr. K. G. Mackenzie, The Texas Co.
Mr. A. E. Pew, Jr., Sun Oil Co.
Dr. J. B. Rather, Socony-Vacuum Corp.
Mr. H. G. Smith, Gulf Refining Co.
Dr. J. B. Terry, Standard Oil Co. of Calif.

It is impossible to visualize a more able or experienced committee than the one which was formed.

Organization of the committee was quite difficult because of the scattered locations of the members and the fact that each of them had extremely important commercial duties. Their membership on the Navy committee was entirely gratuitous and assumed by them as "extra duty." It was possible to hold three meetings of the committee prior to the issuance of the specifications for purchase of fuel oil for use in the fiscal year 1935.

The most difficult points to be determined were the "sludge effect" and a satisfactory test for it. This characteristic was soon understood to cover two effects: that of the action of the oil when passing through heaters prior to burning and the action of depositing wasteful and troublesome sludges in storage either ashore or in ship's bunker tanks. All of the limits of the other characteristics could be determined closely enough analytically using information already on hand or easily obtainable.

The first meeting of the committee was held in Chicago during the American Petroleum Convention. It was soon discovered that meetings would be practically impossible except at such times as the members were drawn to the same place for some purpose connected with their usual pursuits. Technical society meetings presented the best opportunity for such gatherings. At this first meeting it was decided to undertake the development of a test to determine "heater fouling tendency" as the first step to be taken by the committee. "Heater Fouling tendency" supplanted "sludge effect" as the name of the characteristic under investigation. As a beginning, each member undertook to work individually in his own company's laboratories on any possible method which appeared to him to have merit.

The Navy undertook to continue its laboratory work in an effort to determine what oils were satisfactory, questionable, or unsatisfactory. It also agreed to send to a laboratory of each member a representative sample of a satisfactory uncracked fuel oil, a satisfactory cracked fuel oil, and of each unsatisfactory fuel oil which was obtained. Each member also agreed to furnish samples of any fuel oil which he could obtain which in his opinion should prove unsatisfactory in service. It was necessary to have a number of samples of oils of different degrees of satisfactoriness in order that investigation could disclose what characteristic made the oil unsatisfactory and how to measure that characteristic.

At the first meeting it became apparent that although the majority of the Navy's current supply was coming from the West Coast, only one member of the committee represented that district. Commander (now Captain) E. D. Almy, U. S. N., head of the Research Laboratory had become interested in the problem and upon his detachment and transfer to the West coast he volunteered to work up the matter with the California companies. Commander Almy and Dr. Terry formed a sub-committee to the main committee on the West Coast and the members of it joined in the distribution of samples of fuel oil and the cooperative laboratory tests. The members of the sub-committee, of the same high personal calibre as the main committee, were:

Mr. A. G. Marshall, Shell Oil Co.
Mr. R. E. Haylett, Union Oil Co.
Mr. G. F. Olson, General Petroleum Corp.
Mr. C. E. Emmons, The Texas Co.
Mr. J. M. Evans, Associated Oil Co.

Many suggestions were received from members of both committees and from the three Naval laboratories. As a result of these, the skeleton specification was filled in and presented to the second meeting of the committee in January, 1934. A " Fire point " requirement not included in the skeleton was added and the " sludge effect " was replaced by two requirements labeled " Heater fouling tendency " and " Stability in storage."

Following the second meeting, the specifications were revised and issued as a Tentative Specification on 1 February, 1934. The detailed requirements of this specification were as follows:

FREEDOM FROM GRIT: retained as a general requirement but without any specified test or instructions as to how the absence of grit was to be determined. The Navy had been unable to show that grit in fuel oil had been responsible for any difficulties in operation, and the civilian members of the committee had never heard of any case where grit was known to be present in fuel oil and were of the opinion that it could not be after the processing which the oil went through in the refinery. Since any test requirement is bound to add to the cost and difficulty of inspection and the fear of the result of some test probably leads a bidder to boost his price a little to protect himself against loss, the specific grit requirement was eliminated as the first compromise.

FREEDOM FROM ACIDITY: In general the same remarks apply to this item as to the preceding one. In addition, there was no known test of an inspection nature which would reveal acidity in a liquid with the opacity of fuel oil. This requirement was retained in the general paragraph with no specific requirement nor test method.

FREEDOM FROM FIBROUS OR OTHER FOREIGN MATTER: This was retained as a general requirement and in addition it was required that all fuel oil should be strained upon delivery by passing it through strainers of specified design.

SPECIFIC GRAVITY: This requirement was dropped entirely. The only reason for a gravity requirement was to provide for the separation of the fuel oil from any water with which it might become contaminated. A study of the water casualties which the Fleet had experienced in recent years showed that they were reduced in number as the fuel oil burned became heavier. This observation was confirmed by the laboratories. Apparently the only noticeable effect of water contamination of fuel oil is when the water becomes free and collects in large enough globules to extinguish or interfere with the flame. There is less probability of this occurring if the specific gravity of the oil and water are very nearly the same. It was also quite apparent that the trend of refinery technique was definitely toward the production of heavier and heavier fuel oils. If the supply of fuel oil for the Navy was to be kept reasonably adequate it would be necessary either to set the specific gravity limit very low or to leave it out altogether.

FLASH POINT: The flash point requirement was left unchanged at 150 degrees F. to be measured as in the past by the standard method using a Pennsky Martens closed tester.

VISCOSITY: It was decided that the General Specifications for Machinery requirement of full power fuel oil pumping capacity at 700 seconds Saybolt Furol was satisfactory and could be met by all ships in service. The previously recommended temperature at which this viscosity should be reached, 70 degrees F., was also adopted. However, since standard methods of using the Saybolt Furol viscosimeter required use of a temperature of 77 degrees F. (25 degrees C.) and since many laboratories had automatic control for maintaining this temperature, it was decided to use this temperature rather than the slightly lower one. The result was a requirement that the viscosity in Saybolt Furol seconds should not exceed 750 at 77 degrees F.

Study had indicated that all ships in service should be able to deliver fuel oil to the burners at a temperature of at least 185 degrees F. Hence the higher temperature viscosity requirement was set at the upper limit of the efficient atomization viscosity or 150 seconds Saybolt Universal at a temperature of 185 degrees F. Since there was some objection on the part of the committee to the viscosity measurement at 185 degrees F., a non-standard temperature, the following provision was inserted:

> "The supplier may use any method he desires for determining the temperature at which the oil has a viscosity of 150 S. S. U., e.g. he may determine it by viscosity determinations at 77 and 130 degrees F. and a plot on any desired temperature-viscosity chart but the Navy reserves the right to measure the viscosity at 185 degrees F. and to reject if the actual viscosity at that temperature exceeds 150 S. S. U."

WATER: The water limitation was placed at a maximum of 1 per cent to be measured by a standard distillation test instead of the previous centrifuge method. Since there is some possibility that water may contaminate oil when carried in barge or tanker tanks, the following additional provision was inserted:

> "For deliveries by supplier's tankers or barge, oil containing not more than 2.0 per cent of total water is acceptable with a

reduction in price for all water in excess of 1 per cent. The reduction shall be (1.25 times excess water per cent) per cent of contract price."

ASH: The limitation for ash was specified as not to exceed .12 per cent. As there was no standard method of test for ash determination it was necessary to describe the prescribed method in detail.

FIRE POINT: For the first time a Navy fuel oil specification contained a fire point requirement. This was set at a minimum of 220 degrees F. which would permit adequate heating between the heaters and burners without introducing any hazards. Since a little water in oil masks a fire point determination, it was provided that:

"If the water content of the oil prevents an accurate determination of fire point, the oil will be acceptable if the foaming due to water starts below the fire point and at a temperature not lower than 195 degrees F."

This clause made the fire point requirement fairly non-restrictive as far as the oil companies went and provided ample protection to the Navy.

HEATER FOULING TENDENCY: This specification was needed before the laboratory investigation bore definite fruit on the subject of heater fouling tendency. The chemical or physical characteristic responsible for heater deposits had not been identified. It was necessary to accept the protection which a guarantee offered pending more positive laboratory results. The requirement was covered by the following paragraphs:

"The oil shall be free from a tendency to deposit excessively in fuel oil heaters, when being heated for atomization at a viscosity of 150 SS. S. U., for all rates of flow from at anchor to full power, with sudden changes of rate of flow, and with steam to oil heater manually controlled.

"The supplier shall guarantee the oil to meet the requirements of the above paragraph, this guarantee to be based on the supplier's knowledge of 'over-cracking' or 'cutting back' on his own product. In the event that oil furnished fails to meet the guarantee, the supplier agrees to furnish oil of a different type

of method of production immediately he is notified that oil furnished has been unsatisfactory; or to accept cancellation of the contract without liability. The supplier further agrees, that, at any time during the life of any contract which includes this specification; if a satisfactory test is developed to measure 'heater fouling tendency' he will permit substitution of that test for the guarantee here provided."

From a commercial point of view the above requirement provided ample protection to the Navy. From the military point of view, it was a very unsatisfactory compromise but the best possible under the circumstances.

STABILITY IN STORAGE: This requirement like the preceding one could not yet be definitely specified and again it was necessary to accept a guarantee in lieu of a protective test. The guarantee was identical with the above quoted one for "heater fouling tendency." The requirement was:

"The oil shall be free from a tendency to sludge excessively in storage at temperatures from 40 degrees F. to 100 degrees F."

The guarantee was tempered with the following provision:

"The Navy recognizes that storage instability may be caused, in some cases, by water contamination or by mixing fuel oil from different sources in a vessel's storage tanks, which causes are beyond the control of the supplier and are entirely the Navy's responsibility. Where storage instability is manifestly due to one of these two causes the supplier is absolved from all liability."

For furnishing information of historical value and for continuing the laboratory investigations, the following provisions were incorporated in the specifications:

"The contractor may be requested to furnish in quadruplicate to the Bureau of Engineering the following information with each delivery of fuel oil. This information is desired as historical data and will not be used in considering bids nor acceptability of oil delivered."

1. Source of crude from which manufactured (as accurately as is shown by the usual refinery records).

2. Type of fuel oil, whether:
   (*a*) Topped or reduced crude.
   (*b*) Cracking still residuum.
   (*c*) Blended fuel oil.
3. If blended the general nature and approximate percentages of each component such as:
   (*a*) Reduced crude.
   (*b*) Cracked residuum.
   (*c*) Virgin gas oil.
   (*d*) Cracked distillate.
4. Approximate date of final manufacture.
5. Date of tests reported.
6. Any other information considered important in the history of the fuel oil.

"The Navy representative shall take a representative five (5) gallon sample of the fuel oil during delivery. In all cases, this sample together with a copy of the analysis furnished by the contractor shall be forwarded to the Naval Boiler Laboratory, Navy Yard, Philadelphia, Pa."

The tentative specification was used for purchase in April, 1934. As a result of discussions at the third meeting of the committee a few changes were made before the bids were opened. The first of these changes involved elimination of the requirement that the oil be strained on delivery. It had been discovered that, with possibly one exception, none of the probable suppliers had strainer installation and they had no intention of obtaining any. Since the strainers which were installed and used in all Naval vessels, were adequate to protect the burners and other equipment and serious casualty due to the presence of strainable impurities in the oil when delivered were unlikely, and since, further, there was every likelihood that the requirement would not be complied with, it was removed and replaced by the following:

"Bidders shall state whether or not the oil is strained on delivery or at any point before delivery. This statement is required for information only."

Based on the experience of the members of the committee and of personnel from the Navy's laboratories who were present at the meeting, the fire point determination was eliminated for all fuel oil whose flash point exceeded 175 degrees F. This was based on the agreement that the margin between flash point and fire point, although neither constant nor regular, was, in all cases, sufficient to insure a safe oil if the flash point was at least 175 degrees F. Elimination of any unnecessary test was of course to the advantage, both of the Navy and the oil suppliers.

The wording of the "Ash" determination test was changed somewhat to clarify it technically. There was no change in substance.

At this same meeting, the progress of the investigation was discussed. Several tests for heater fouling tendency had been suggested and copies of these were furnished to all members for their study. It was decided that large (carload) samples of as many unsatisfactory oils as were obtainable of the small samples which were being furnished by committee members would be shipped to the Boiler laboratory for service test.

Toward the end of 1933, it became apparent that the division of the Navy's investigatory laboratory work between three different laboratories was not the best arrangement possible. Much of the same testing work on each sample was done by each laboratory and this duplication was unnecessary. It was also, quite a problem to get the desired distribution of oil samples. Because of the importance of fuel oil to the Navy, and the need for continuing methods of safeguarding the quality of the fuel oil supplied as a permanent thing, it had been decided to complete the work on the eighteen large samples already started at the three laboratories, and then to close out the fuel oil work at the Research Laboratory and the Engineering Experiment Station, thus confining the fuel oil investigation to the Boiler laboratory. The necessary alterations to the buildings at Philadelphia, assembling of equipment, and personnel were completed in the Spring of 1934 and the Fuel Oil Section of the Naval Boiler Laboratory established for the purpose of continuing the Fuel Oil Investigation on a permanent basis.

The tentative specification described above was used for purchases on the East Coast where theretofore fuel oil had been pur-

chased on a Bunker "A" specification. On the West Coast, assurance was not yet on hand to permit elimination of the artificial but effective protection of the specific gravity limitation, and on the insistence of the forces afloat this was retained.

In May, 1934, the author was detached from the fuel oil desk in the Bureau of Engineering. Pending arrival of Lieutenant A. C. Murdaugh, Commander Howard S. Jeans, U. S. N., head of the Specifications Section of the Design Division, took over the details of the fuel oil desk. At this time the Research Laboratory and the Experiment Station had practically completed their part of the work on the 18 large samples and the work of correlating all of the data now available devolved upon the Boiler Laboratory, which under Lt. Comdr. T. A. Solberg, U. S. N., with Mr. R. C. Brierly and Mr. Ashton Howarth, test engineers was to continue the fuel oil investigation indefinitely.

Application.

The general policy of application which was adopted prior to the World War remained and still remains unchanged. For all combatant types of vessels, only fuel oil was to be provided. This policy has not been questioned and will not be until something better appears on the scene.

The United States came out of the war with an oil-burning fleet except for some of the older battleships and cruisers, and a few auxiliaries. The end of the coal-burning units was hastened by the Limitations of Arms Treaty signed in Washington on 6 February 1922. By the terms of this Treaty all of the battleships older than the *Utah* and *Florida* were immediately scrapped. The limitation on number of battleships and the shift of international competition in Naval vessels from numbers to quality of the individual unit, necessitated the modernization of all battleships retained. This country was a little slower to realize this than were England and Japan but eventually the work of partial modernization was authorized and taken in hand. Part of the modernization program was the conversion of all battleships to oil-burning. This was accomplished on the *Utah, Florida, Arkansas, Wyoming, New York* and *Texas* bringing the battleships up to 100 per cent oil-burning.

The war had proved the weakness of the armored cruiser type so its demise was quite rapid. These vessels as well as the cruisers

of the *Chester* class and the cruisers or gunboats of the *Denver* class were rapidly eliminated by obsolescence and wearing out. The coal-burning auxiliaries were converted to oil-burning as rapidly as funds would permit.

The conversion of the Fleet to 100 per cent oil-burning was accomplished in 1932 when the *Rochester* was decommissioned. The first oil-burning installation in a combatant vessel of the United States was authorized in the *Cheyenne* in 1906. Twenty-six years later the change from coal was complete. Probably, but for the World War and the Washington Treaty, the conversion would have taken a much longer time. At least that length of time will probably always be needed to effect the complete substitution of any modern innovation for an older means of accomplishing some Naval purpose.

Some investigation of the use of pulverized coal for marine installations was made by the Fuel Oil Test Plant in 1926 for the United States Shipping Board. No serious thought was given to the application of this fuel for naval vessels. The method of reducing coal to a fine form for combustion found application in a few commercial marine vessels but its use has not become at all general.

The trend for some years has been toward the use of Diesel engines. This trend has been quite definite for merchant vessels and may some day become generally applied to combatant vessels. The fuel will still be oil and its source as long as it lasts—petroleum.

A NEW "SHEET FLOW" HYDRAULIC RUNNER.

By Henry F. Schmidt, Honorary Member.*

The efficiency of hydraulic rotors depends upon accurate design and precise production of geometric surfaces. Compromise contours to promote strength are required for high speed rotors. In this article Mr. Schmidt describes a method of accomplishing these criteria. In addition he offers a welcome simplicity of procedure.

In general, hydraulic rotors having warped blades are usually referred to as of the Francis vane type and their design has been hidden behind a veil of mystery.

The result which the Francis vane rotor is intended to accomplish is the production of passages such that the separating partitions have at every point of the inlet and outlet the desired angles to provide tangential inlet at every point of the inlet edge, the surfaces being such that all stream lines are continuous from inlet to outlet without sudden changes of acceleration and direction.

Endeavoring to make a very high speed rotor in which the inlet edges of the blades would be radial so as to act as spokes to help support the blade ring, and still have the correct inlet angles at all points, and also have the desired continuity from inlet to outlet, the writer originated the following automatic method of producing warped or Francis vane runners.

The method of generating the blade form is shown in Figure 1 which shows a wooden disc representing the disc of a warped blade rotor. The disc has a hole at its center through which a mandrel extends, carrying a radial arm which in turn carries a movable arm to which is attached a sweep as shown.

* Westinghouse Electric and Manufacturing Company.

When designing a pump, turbine or blower, the axial velocity through the eye of the rotor and the peripheral velocity having been fixed, the velocity diagrams may be laid down for finding the angle which the blades make at the entrance or exit to the rotor along the surface of the rotor disc. Next, one or two other points are located along the blade path and the curve of the blade at its intersection with the disc may be laid down as shown in Figure 1. If we now cut a groove in the rotor disc representing the intersection of the blade with the disc, and the sweep (of a diameter equal to the desired blade thickness) is then caused to follow this groove, the sweep will generate a continuous surface or sheet every element of which has the theoretically correct angle.

In the model Figure 2, a sweep representing the inside contour of the blade ring is employed for sweeping up in any suitable material (in this instance, modeling clay) a mass having the form of the volume between the blade rings and the blade disc. Then, as shown in Figure 1, the blade surface sweep is passed through the mass produced by the shape sweep, thus producing the blade forms as shown in Figures 1 and 2. This indicates the reason for referring to this type runner as a "sheet flow" design; which will be obvious since ordinarily in the process of designing a warped blade rotor, it is attempted to follow a single stream line through from entrance to exit; whereas in this process, instead of dealing with a single stream line, a complete "stream sheet" is automatically produced mechanically in one operation.

That the form thus produced is theoretically correct will be evident, since any point on the sweep travels circumferentially a distance directly proportioned to its radius about the center of the mandrel; hence, it is obvious that every point along the sweep traces a blade angle such that, with a constant axial velocity distribution over the inlet or outlet area, the motion of the sweep draws the hypotenuse of the velocity diagram; that is, it travels in such a manner as to provide tangential inlet or outlet at every point along the blade. It is also seen that because of the sweep method of generating the surface, there can not be any discontinuities along a stream line or between adjacent stream lines.

It may be pointed out that this same process of producing the blade shape can be used to produce anything from a straight radial

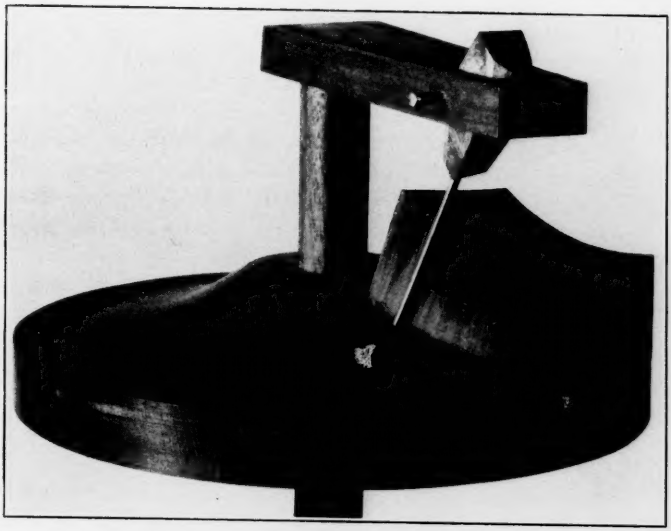


FIGURE 1.

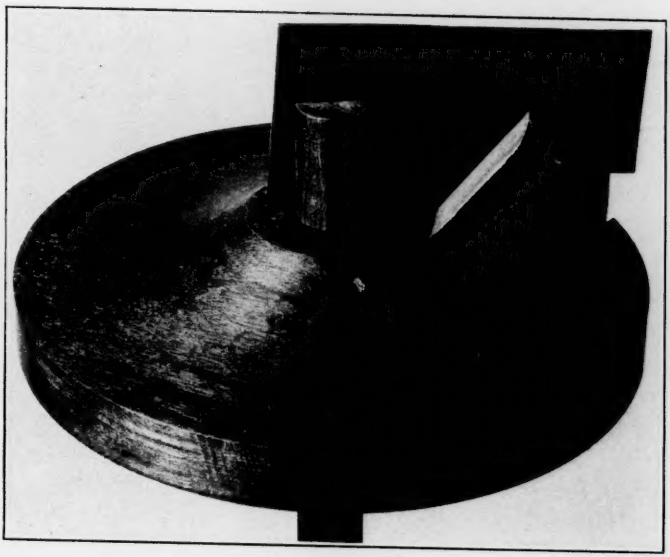


FIGURE 2.

FIGURE 3.

flow centrifugal impeller (the radius of the sweep being very long) to a pure axial flow impeller (or screw propeller) depending entirely upon the radius of the sweep arm and the shape of the disc or hub and groove which the sweep follows.

It should be noted that the sweep may be bent in any shape to produce any kind of warped surface. If the angles of the groove it follows are correct, all the angles of the blade will be theoretically correct; and, neglecting very slight changes in friction because of increased area, all would have the same efficiency, though they may look so different that it would be impossible to recognize them as the same thing hydrodynamically.

In very high speed rotors for pumps or blowers, a very important feature is that it permits the design of radial or substantially radial inlet edges to support the rim which may travel at tangential speeds which would be impossible because of excessive hoop stresses.

To demonstrate this method of producing warped blade rotors, the writer built a small pump which, however, was tested as a blower because of convenience.

Using the form shown in Figure 1 and Figure 2, a die was made for bending the blades by casting a low melting point metal against the modeling clay blade form. The rotor shown in Figure 3 was made of celluloid. The disc and blade ring were built up of layers of one-eighth inch material cemented together with acetone and then turned to the desired dimensions shown in Figure 4. In Figure 4, the angles indicated along the root of the

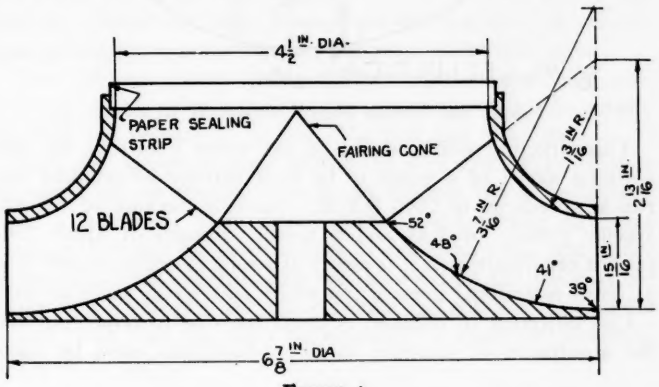
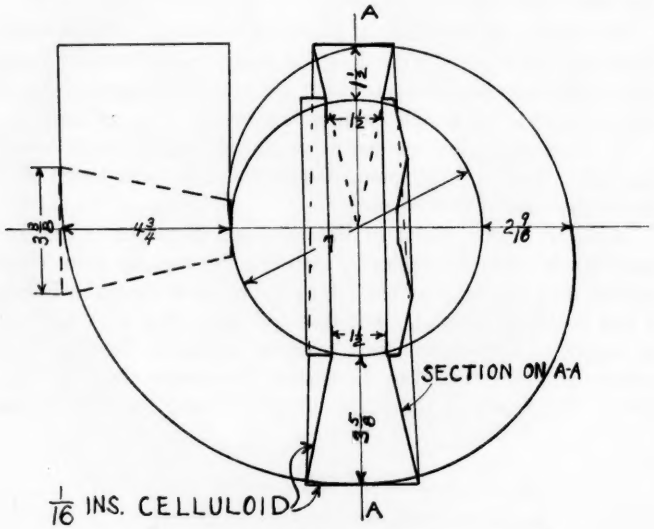


FIGURE 4.

blade show the angle between the blade and the tangent at the point indicated. These angles were used for constructing the sweep guiding groove.

The blades for the rotor were cut out to the required shape of one-sixteenth inch celluloid which was then bent to the shape of the die by means of elastic bands and dipping in boiling water until they assumed the form of the die, after which they were set by holding under cold water while still on the die. The blades were then assembled between the disc and blade ring and cemented with acetone.



CASING FOR "SHEET FLOW" HYDRAULIC RUNNER.

This structure which, so far as the writer knows, is the first working model of a pump to be built entirely of celluloid was run at speeds up to 7000 R.P.M. Actually, because of the low specific gravity of 1.45 and a tensile strength of about 7000 pounds per square inch, it is nearly as strong as ordinary mild steel as far as centrifugal stress is concerned, and is very easily worked.

One objection to celluloid is distortion due to cementing and the absorption of moisture so that precautions must be taken

during fabrication to prevent distortion. In the future the writer would use metal inserts in appropriate places. However, except that the rotor developed a wobble which may have reduced the efficiency a per cent or two, the blade shape and angles were not materially affected by distortion.

For test, the rotor was overhung on the end of the shaft of a ¼ H.P. motor, the frame of which was mounted in ball bearings so as to serve as a reaction dynamometer. This avoided the use of shaft bearings external to the dynamometer.

The brake arm was 3.6 inches and rested on a Toledo scale readable to 1/10 ounce and calibrated with standard brass weights.

The speed was taken with a calibrated hand tachometer and the pressures measured by means of inclined gauges.

An intake nozzle with rounded entrance and piezometer ring connected to an inclined gauge was used for measuring the volumes. The nozzle was checked to obtain the nozzle coefficient by means of an impact tube traverse which showed the coefficient to be about 99 per cent, so a value of .98 was used for calculating the volumes from the piezometer readings. The diameter of the piezometer ring was 4.53 inches and its length 9 inches. There was no rotation at the throat of the meter at any capacity within the range of the tests.

Static pressure created by the blower was measured in a box at the end of a two-foot length of discharge duct.

Impact readings were taken in the discharge duct and it was found that the averaged total head obtained from the impact tube readings checked the static pressure in the box plus the velocity head calculated from the volumes measured at the inlet meter.

Two different rotors having different inlet angles were constructed, one of which was also tested progressively as the outside diameter was reduced by turning off a half inch at a time.

As is well known, leakage around the inlet ring of the rotor is the cause of the greatest loss in an efficient pump or blower. After a number of trials, a thin Bristol board packing strip was glued to the rotor (to avoid danger of fire from rubs) and a ten-thousandths thick celluloid strip was fastened on the inside of the intake ring which gave very good results and only the tests on the second rotor with the paper packing strip is therefore presented in Figure 5 (curve).

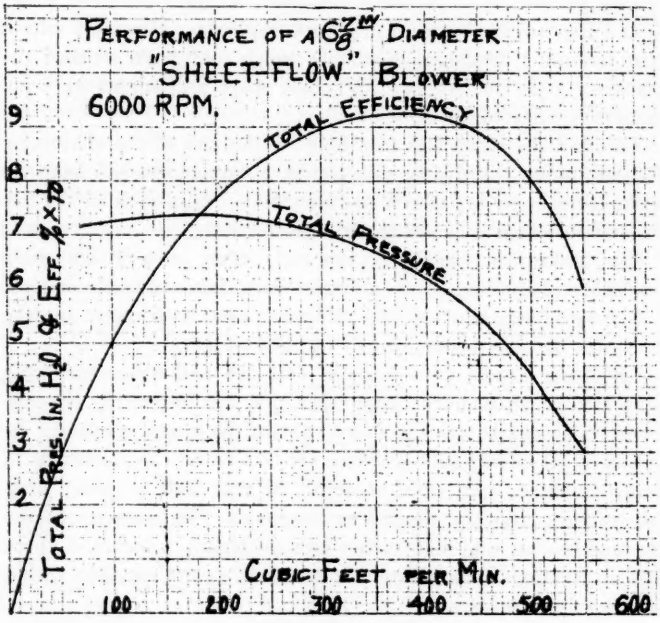


FIGURE 5.

An examination of Figure 5 shows very desirable characteristics of a good total head delivery curve and a very rounded total efficiency curve which it will be observed reaches 92 per cent and is above 90 per cent over a range of considerable volume. The tests were repeated by three different observers.

The casing used for this test was of conical design having a discharge area of 12.2 square inches of trapazoidal form.

So far as the writer is aware, the efficiency obtained from this pump, tested as a blower, equals the best efficiencies of pump of any head and capacity thus far reported. Yet, except for the tests to adjust the paper packing strip, this result was obtained without any previous research, without any elaborate calculations and was the *first warped blade* rotor of any kind which the writer has designed. The results are not the results of research

or the application of hydromechanics but merely the result of a theoretically correct mechanical method of design and construction.

In closing, it may be pointed out that by this method, it is possible to produce rotors milled out of the solid since it will be quite apparent that if in place of the sweep, we substitute a rotary cutter arm with a motor to drive the cutter and employ a suitable train of gearing for rotating the shaft or mandrel and imparting the swinging motion to the sweep, any type or form of warped blade rotor may be produced entirely automatically without even a drawing, except for the disc and blade ring profiles. Such a machine could produce anything from a ship's propeller to a radial bladed "tin plate" type of fan.

NOTES.

INDEX TO NOTES.

DEVELOPMENTS IN ALLOY SECTIONS AND TUBES FOR MARINE ENGINEERING.
—Transactions of the Institution of Engineers and Shipbuilders in Scotland, Glasgow, Scotland, February, 1939.

THE FLOW OF COMPRESSIBLE GAS.
—Journal of the Franklin Institute of Pennsylvania, Philadelphia, Pa., January, 1939.

TWO SPEEDS WITH ONE MOTOR.
—Power, New York, N. Y., March, 1939.

INVISIBLE GLASS.
—The Technology Review, Massachusetts Institute of Technology, Cambridge, Mass., January, 1939.

GLARELESS GLASS.
—General Electric Review, Schenectady, N. Y., February, 1939.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

The *Asama* Comes Back.
—Motorship and Diesel Boating, New York, N. Y., February, 1939.

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—The Aeroplane, London, England, December 14, 1938.

Application of Supersonic Waves.
—The Metallurgist (supplement to The Engineer), London, England, December 30, 1938.

Some Aspects and Problems of the Development of High-Speed Craft and Its Machinery.
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Latest Developments of the Benson Boiler.
—Mechanical Engineering, New York, N. Y., March, 1939.

DEVELOPMENTS IN ALLOY SECTIONS AND TUBES FOR MARINE ENGINEERING.

Modern metallurgy is responsible for providing an enormous variety of materials, and a great wealth of data relating to the properties of these materials. It is the high duty of this publication to present such data in an available form to shipbuilders and engineers. The following is abstracted from the paper by A. B. Graham of Henry Wiggin and Co., Ltd.; published in the Transactions of the Institution of Engineers and Shipbuilders in Scotland, February, 1939.

It is becoming more and more evident that engineers especially should have a wide knowledge of materials, their characteristics, and their uses. Ships are now required to have greater speed, and higher power for less weight with equivalent or greater safety. The space occupied per horsepower developed must be a minimum. Along with these is demanded increased efficiency, increased reliability, the minimum expenditure on upkeep, and finally, improved appearance from the decorative or purely aesthetic point of view.

It is with these thoughts in mind that the Author proposes to discuss some recent developments in alloy materials, in respect of their constituents, properties, and practical applications. Also, as it is bound to be advantageous to the designer to have some knowledge of the methods employed in producing the parts which he utilizes, some of the recent advances in this field will be described. It will obviously be impossible in this paper to cover more than a portion of the ground embraced by its broad title. The number of alloying elements used in ferrous and non-ferrous materials is very large and is being added to daily. There are 30 known metals, yielding 534 binary alloys and 4060 ternary alloys. In the ferrous field alone, a steel maker mentioned the other day that he was handling at least 120 distinct brands of alloy steel, while in the non-ferrous field, we have in recent years seen the rapid strides made in the development of nickel, chromium, aluminium and magnesium alloys. In order, therefore, to bring the subject within limits, it is proposed to deal particularly with some recent developments relating to alloys in which nickel appears as an essential constituent, due, of course, to the Author's association with the development of this type of alloy. Even reduced to this extent, it will only be possible to deal with a few of the nickel-bearing alloys, of which there are actually 2300 bearing trade or proprietary names.

TABLE I.

PERCENTAGE COMPOSITION OF SOME NICKEL ALLOYS.

Material	*Nickel*	*Copper*	*Chromium*	*Zinc*	*Iron*	*Aluminium*
Monel	68	27	—	—	—	—
"K" Monel.....	67	29	—	—	—	2.75
Inconel	80	—	13	—	6	—
Cupro-nickel	30	70	—	—	—	—
" "	20	80	—	—	—	—
Nickel silver	20	62	—	18	—	—

The principal alloys coming under this category are Monel, "K" Monel, Inconel, cupro-nickel and nickel silver. It is not proposed to give a complete analysis for each of these, but Table I gives approximate details of the essential metals present in the alloys whose uses and methods of fabrication will be discussed. A few general notes on the composition and properties of these

materials will no doubt be useful at this stage. Of the alloys referred to, probably the one so far most familiar to engineers and shipbuilders is Monel.

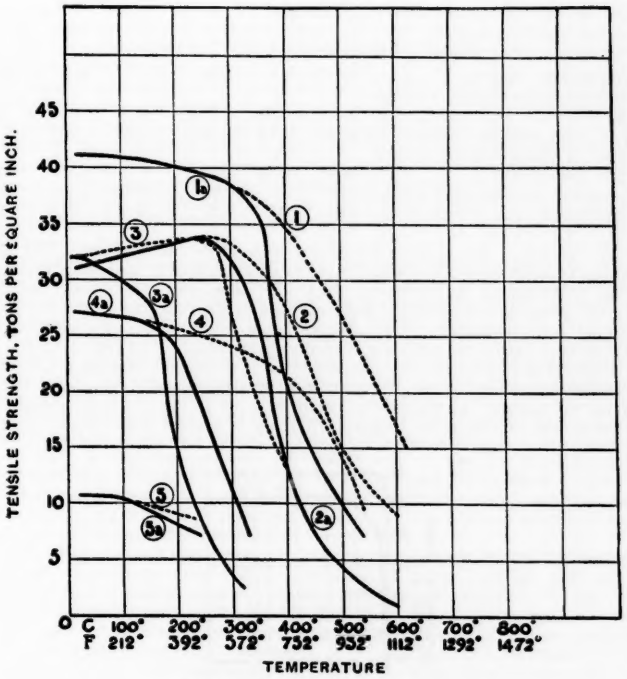
Monel. This material is unique in that it is a natural alloy. The ore as mined in the Sudbury district of Canada, contains approximately 2½ per cent nickel with 1½ per cent copper, so that the essential constituents are present in the same ratio as in the finished alloy. Since there are bound to be some variations in the nickel-copper percentages obtaining in the ore, nature must be allowed a working tolerance. This is reflected in the Admiralty and other specifications for the material, which allow a variation of plus or minus 2½ per cent on 67½ per cent nickel. It should be noted, however, that within that range of nickel content, there is no appreciable variation in the mechanical properties or corrosion resistance of the alloy.

Monel is highly resistant to corrosion from numerous acids and alkalis. It is particularly suitable for use in contact with sea water and is being used in this connection for such parts as motor boat propeller shafts, bolts and nuts exposed to sea water or spray, and the like. Its rustless qualities find applications in steam-driven ships, in superheater internal fittings, nuts for securing turbine nozzle plates in impulse turbines, boiler drain plugs, valves and valve spindles. In Diesel engines, it is applied in such forms as hollow studs through the water spaces for cylinder lubrication, cylinder head cooling tubes, circulating pump valves, piston cooling tubes, and impellers for circulating pumps. In air compressors, valves and valve spindles of Monel are commonly fitted.

TABLE II. MONEL.

Condition	*Maximum Stress tons per sq. in.*	*Limit of Proportionality tons per sq. in.*	*Elongation per cent on 2 in.*	*Reduction of Area per cent*	*Brinell Hardness*
Hot rolled	34	12	30	60	140
Annealed	31.3	11.8	50	72	120
Cold Drawn. 26 per cent reduction in area	50.2	13.6	19.5	64	200
Cold Drawn. 26 per cent reduction in area and stress relief annealed	52.3	31.2	22	60	205

It is obvious that good corrosion-resisting properties alone are not sufficient to make the material suitable for many of its applications and that good mechanical properties also are required. Table II shows that Monel has these qualities to a very marked degree. It is established that within the range of compositions (from 60 to 70 per cent nickel) the optimum physical properties of this series are obtained. Figure 1 shows how Monel compares with some other materials under varying conditions. Its hot working range is from 870 to 1150 degrees C., and its annealing range from 600 to 950 degrees C. Stress relief annealing is effected by prolonged soaking at 300 degrees C. It cannot be thermally hardened, and as the table shows, its mechanical properties are dependent on the amount of cold work applied. In the hot condition it is, like most nickel alloys, susceptible to sulphur or, where sulphur is present, the metal must be suitably protected from the products of combustion. It can be welded both electrically and by gas, and recently in this respect the technique of electric welding has been greatly improved so that autogenous and resistance welding can be carried out with complete success. At room temperature the material is only slightly magnetic.



Metal	Quick Break Test Maximum Strength	Limiting Creep Value	Source
Monel metal	Curve — 1	Curve — 1a	Monel-Weir Ltd., & Brown
Mild steel	Curve — 2	Curve — 2a	Monel-Weir Ltd., & Lea
H. T. brass	Curve — 3	Curve — 3a	Brown
Phosphor bronze	Curve — 4	Curve — 4a	Brown
Aluminium	Curve — 5	Curve — 5a	Brown

FIGURE 1.—STRENGTH OF METALS AT HIGH TEMPERATURES.

TABLE III.

"K" MONEL.

	Yield Point tons per sq. in.	*Maximum Stress tons per sq. in.*	*Elongation per cent on 2 in.*	*Izod ft.-lb.*	*Brinell Hardness*
Hot rolled and softened..	19	39	35	100	140
Hot rolled, softened and thermally hardened.....	43	60	30	70	270
Cold worked and thermally hardened	60	72	15	50	320

TABLE IV.

"K" MONEL: STRENGTH AT HIGH TEMPERATURES.

Temperature, degrees C	25	95	205	315	425	540
Maximum stress, tons per square inch	73.6	72.8	69.6	65.9	55.8	55.6
Yield point, tons per square inch	55.8	55.4	52.7	48.5	47.3	45.9
Limit of proportionality, tons per square inch	46.9	46.4	44.6	37.5	36.3	31.5
Elongation, per cent on 2 inches	21	21	20	19.5	18.5	9.5
Reduction in area, per cent	38.9	37	35	32.8	29.8	9.8

"K" Monel. This alloy is a modified form of ordinary Monel. The aluminium addition shown in Table I renders it non-magnetic and heat treatable. While retaining all the corrosion resistance characteristics of Monel, its mechanical properties are greatly improved due to the fact that it can be hardened by heat treatment. "K" Monel is an alloy of the precipitation or artificial age-hardening type, the hardening consisting of heating the material for a period at a relatively low temperature. It is thought that the mechanism of hardening consists in the precipitation of an inter-metallic compound in the crystal slip planes. In the normal conditions, hardening is almost completed in two hours. Heating for longer periods up to sixteen hours gives slightly

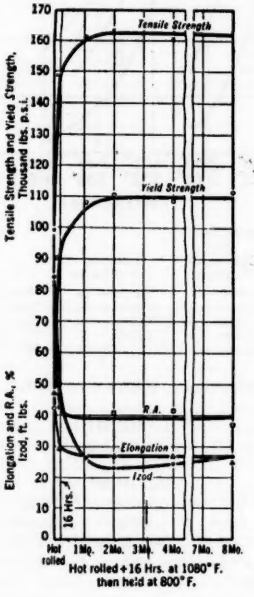


FIGURE 2.—MECHANICAL PROPERTIES OF "K" MONEL.

increased hardness, but for all practical purposes, hardening may be taken to be complete after four hours' heating. The hardening effect becomes apparent at 400 degrees C. and progresses most rapidly at 590 degrees C. Above this temperature, annealing commences.

It should be noted that to obtain the best results from the heat treatment, the hot operation prior to the final heat treatment should consist of heating to 820 degrees C. and cooling rapidly, preferably by a water quench.

One of the most interesting features of "K" Monel is that the hardening temperature is below the annealing temperature. It is possible, in consequence, to superimpose thermal hardening on work hardening.

Table III shows typical mechanical properties obtained by the standard treatment, and Table IV shows how these vary under varying temperature conditions.

A question that naturally arises is: Does age-hardening continue in the alloy after it has been put into service, if there happen to be suitable temperature conditions, so that the metal might become embrittled? The curve shown in Figure 2 indicates that up to the end of the first month, some very slight further precipitation does take place, but after that, a condition of equilibrium is attained and further hardening ceases. It will be observed that optimum values in all cases are obtained by superimposing thermal treatment hardening on hardening already present in the material due to cold work. When thermal treatment alone is carried out on material in the soft annealed and quenched condition, the values are lower. In the hardened condition this material is quite easy to machine, and any part made from it may be finish machined first and then heat treated. As the heat treatment temperature is low, no scaling takes place, the metal being only slightly discolored, and if special precautions are taken it is quite possible to carry out the heat treatment without any discoloration whatsoever.

The alloy is relatively new, but already it is supplying the answer to a number of problems where high corrosion resistance, coupled with exceptionally high physical properties and hardness, are required. It has been applied in such cases as sleeves for centrifugal pump shafts operating with sea water. Due also to its non-magnetic properties, it is largely employed for parts adjacent to ships' compasses, and in aircraft and seaplanes this has been found to be very important. This alloy has also definite potentialities as a material for turbine blading, apart from the fact that it costs only slightly more than ordinary Monel. Service trials of "K" Monel turbine blades are now in progress, and it is hoped that in the near future authentic data will be available that will justify the confidence felt in the material for this purpose. Another interesting application is for balls and ball races. Where these have to operate in contact with sea water this alloy effectively resists corrosion and can be hardened sufficiently to ensure that the balls preserve their shape under heavy loading.

Inconel. This alloy is the newest of the group under consideration. It is of the nickel-chromium type and has high heat-resisting properties, coupled with extraordinary resistance to corrosion. It has also higher mechanical properties than ordinary Monel in the cold-worked condition. Mention is made of this alloy only to bring it to the notice of those interested. Its main application so far has been in the electrical and aero engine fields. It is not heat treatable and has, like Monel, to depend on work hardening to develop hardness and tensile strength. So far, it has not been used to any extent in marine engineering practice, but investigations are at present proceeding in this connection and some interesting results are anticipated. As an indication of the type of application where Inconel is being used to great advantage, reference may be made to its use for aero engine exhaust manifolds. In this connection, it is now being applied, not only for its corrosion resistance properties, but also for its resistance against the corrosion effects experienced

when using fuels with a high octane value. As will be seen from Table II, it is extrudible, although considerable care has to be taken in doing this. It can be cold worked by the usual methods, but considerably more power is required for these operations, and tools of very special material must be employed. At present, large quantities of tubes of small diameter for the electrical industry are being produced from this material, but the present methods cannot be considered to have reached finality, and while tubes up to about 3 inches in diameter can be manufactured satisfactorily by the present methods, considerable development work is still in progress.

Cupro-Nickel. The alloys already mentioned bear what are more or less trade names, and refer to specific and distinct materials. The name "cupro-nickel," however, can be applied literally to any alloy containing nickel and copper in combination, and to identify them, it is necessary to prefix some indication as to the amount of nickel and copper present. The two most familiar alloys of this type are those containing 30 and 20 per cent nickel and 70 and 80 per cent copper, respectively. They have been in existence for many years and could be classed as relatively old alloys. The most outstanding example of their application is that of condenser tubes, and this will be referred to in detail later. These alloys are not of the thermal-hardening variety in their ordinary form, but depend for their physical properties and hardness on cold working in the same way as Monel.

Nickel Silver. The nickel silver alloys, of which there is a large variety, are probably better known to engineers as German silver. The name itself has come down from an age when metallurgists were not so precise in their estimation as they are now. Actually, there is no silver in these alloys except, shall we say, as an impurity, and the name appears to have been adopted purely because of the silvery appearance which these alloys have to a greater or less degree. The principal constituents present are nickel, copper and zinc. It has become accepted practice to identify variations of these compositions by prefixing the percentage of nickel present, and so there is a whole range of nickel silver alloys varying from 7 to 30 per cent nickel silver.

One of the large applications of this material is in the decorative field, and it is of interest to the shipbuilder rather than to the engineer. Of late years, it has been coming into favor for external decoration, due to its pleasing color and resistance to atmospheric corrosion, and for interior decoration it is being employed in considerable quantities for stair hand rails, balustrades, doors, etc. Until recent years alloys containing from 10 to 12 per cent nickel have most commony been used for this purpose, and while these have a very beautiful appearance, there is a tendency for the material to turn somewhat yellow in color if not regularly cleaned. It has been found that an increase in the nickel content is beneficial in minimizing this discoloration, and at the same time giving a better original color to the material. In this field, a large part of the demand is for extruded shapes, and while sheets and strips were available, due to the difficulty of extruding nickel silvers with more than 12 per cent nickel, this determined the extent to which alloys having a higher nickel content could be employed. During the past year, however, considerable work has been done in Glasgow to overcome this, and it is now possible to obtain extruded shapes in nickel silver alloys containing up to 20 per cent nickel. This is fortunate, because for decorative purposes, an alloy containing 20 per cent nickel represents the optimum point, after which further additions do not appear, at the moment, to confer appreciable improvement in color or appearance. This material does not work-harden rapidly like some of the other alloys referred to; it is easily fabricated and can be welded satisfactorily, provided proper precautions are taken. The question of mechanical properties rarely arises in connection with the type of work for which these are used, but Table V indicates what can be obtained if required.

TABLE V.

TENSILE PROPERTIES OF NICKEL SILVER.

Grade	*Condition*	*Tensile Strength tons per sq. in.*	*Elongation per cent on 2 in.*
30	Hard	58	2
	Annealed	33	32
25	Hard	49	3
	Annealed	32	40
20	Hard	50	3
	Annealed	28	40
18	Hard	42	3
	Annealed	26	33
18	Hard	48	2
(telephones)	Annealed	31	30
10	Hard	41	4
	Annealed	24	48

The various characteristics and applications of these materials having been briefly reviewed, some developments in connection with their preparation into forms which can be utilized by engineers and shipbuilders can now be considered.

Sections. These divide themselves into two main categories, namely, (1) sections applied to power plant and engineering generally, and (2) sections of more or less decorative character which are of more interest to the shipbuilder than the engineer. Into the first category come ordinary rounds, squares, flats, hexagons, angles, and the like; and in the second may be grouped hand rails, balustrades, panels, beadings, etc. The sections in the first category have been available for many years in Monel, cupro-nickel and, to some extent, nickel silver. These were produced by methods more or less in line with steel works practice, that is, by hot rolling or forging.

TABLE VI.

SECTIONS EXTRUDIBLE IN NICKEL ALLOYS.

Material	*Engineering Sections*	*Decorative and Shaped Sections*	*Tubes*
Monel	Rounds, Flats, Squares, Ovals, Angles, Hexagons	A few	Yes
"K" Monel	Rounds, Flats, Squares, Hexagons	None	Yes
Inconel	Rounds, Squares, Hexagons	None	Yes
20 per cent Nickel Silver	As Monel	A large variety	Yes

In 1930, experiments were begun with a view to determining if these alloys would extrude. Monel, being the material most in demand, although obviously likely to be the most difficult, was the first to be tried. These experiments, carried out on an ordinary geared drawing press, showed sufficient promise to justify putting down a proper extrusion unit. This was done and, by 1933, the extrusion of Monel had become standard practice. Later experiments on the other alloys have been equally successful. Incidentally, it may be mentioned that the first stainless steel tubes extruded commercially anywhere were extruded on this press, many tons being manufactured before the production was handed over to the steel tube business, where it belonged. It must not be imagined, however, that because all the ordinary engineering sections are extrudible, anything and everything can be extruded. Some day, it is hoped, this may be possible, but in the meanwhile, the position is generally as shown in Table VI.

At this point, a short description of the extrusion presses now installed in Glasgow to produce sections and tubes in these alloys is perhaps appropriate. There are four, namely, two vertical presses of 400 tons and one of 600 tons, and one horizontal press of 2500 tons capacity. The 600-ton press is the original on which the development of the extrusion of these very hard alloys took place. The 2500-ton press, installed about a year ago, was laid down fundamentally to develop the supply of nickel silver shaped sections and give much-needed added capacity for the supply of ordinary sections and large tubes in nickel, Monel and Inconel. This machine is the first extrusion press of this type and size to be built in Britain. Usually these machines are obtained from Germany, and it is very gratifying to know that this is not now necessary. The hydraulic pressure employed in all instances is 200 atmospheres, and for economic reasons all the idle movements of the presses are made with low-pressure water.

The three small presses have no piercing rams, but the large horizontal press has piercing equipment of the very latest type. All the presses are specially rigid in view of the heavy duties put upon them. Heating of the billets is carried out in oil-fired furnaces using low sulphur oil, and these can take billets from 3 to 11 inches in diameter. An interesting feature of the furnace for the large press is the employment of the waste heat from the furnace gases to heat the container block.

The heaviest billet extruded on the large press so far weighs 180 pounds and measures 7 inches in diameter by 15 inches in length, but the press can take a 250-pound billet. Containers are also available to take 5- and 6-inch diameter billets. Nickel alloys are extrudible in these presses at temperatures ranging from 850 to 1200 degrees C., the nickel silvers being extruded at the lower temperature, whereas Monel and Inconel are worked at the higher temperatures. It may be taken as a general rule that as the nickel content of the alloys increases, the extrusion temperatures must also be increased. The same is true of the specific pressure of extrusion, so that whereas for nickel silver a specific pressure of 50 tons per square inch may be sufficient to extrude the metal at a given extrusion ratio, 75 and even 80 tons per square inch is necessary for some of the higher nickel alloys. It should also be noted that the extrusion ratio, which is the ratio of the cross-sectional area of the extruded product to the cross-sectional area of the initial billet, is higher for these materials than for the brasses. Speed of extrusion is also of great importance and in the majority of cases extrusion is carried out at high, rather than at low, speed. The presses referred to have all been designed with these factors in view. Apart from the various commercial sections referred to above, probably the most familiar to marine engineers is turbine blading.

TABLE VII.

COMPARISON OF MECHANICAL PROPERTIES OF MONEL AND STAINLESS IRON TURBINE BLADES.

	Maximum Stress tons per sq. in.	*Yield Stress tons per sq. in.*	*Elongation per cent on 1 in.*
Monel	39.1	35.9	20
Stainless iron	25.5	20.1	24

Turbine Blading. One of these alloys, namely, Monel, has been used for the manufacture of turbine blading for many years, and it is an ideal material for the purpose. It has the necessary corrosion-resisting properties for marine turbine requirements; it has great stength, coupled with good elastic and impact values; it is very resistant to erosion by steam, since it can be work-hardened sufficiently to make it resist all but the most severe conditions; it is easy to fabricate either by machining into solid blades, or building into segments by the use of steel packing pieces, since it silver-solders easily. Brazing, especially pot brazing, is not recommended for Monel segments. Blading is supplied now in two types, namely, in the familiar strip form where the sections may be in lengths up to 15 feet, and more recently, as integral root blades where the blade is fitted to the turbine without separate packing pieces, each blade having the packing piece integral with it.

TABLE VIII.

CREEP TESTS AT 800 DEGREES F. (426 DEGREES C.) (TIME—300 HOURS).

Strain per cent	*Time Hours*	*Monel Bar tons per sq. in.*	*Stainless Iron tons per sq. in.*
0.06	1,000	8.3	7.9
	10,000	7.5	6.5
	100,000	6.8	5.2
0.08	1,000	8.7	8.4
	10,000	8.0	7.0
	100,000	7.4	5.7
0.10	1,000	8.9	8.8
	10,000	8.4	7.4
	100,000	7.8	6.0
0.12	1,000	9.2	9.2
	10,000	8.6	7.8
	100,000	8.0	6.5

The extrusion developments already referred to have played a considerable part in accelerating the development of strip blade manufacture. As a rule, this type of blading is cold rolled from extruded flats or formed sections. Annealing takes place between the various cold passes in the electric bright annealing furnace, and the final pass is so arranged that the blades go into use containing approximately 10 per cent cold work, this being sufficient to give the most suitable mechanical properties. Typical figures for Monel blading compared with those for stainless iron are given in Table VII. These results were obtained by pulling complete blades of similar section sawn out of finished segments; silver soldering was carried out on the Monel blading, and brazing, with subsequent annealing, on the stainless iron. The packing pieces were cleaned off by filing so that they would not affect the results.

There is a general tendency in these days for steam temperatures to rise due to additional superheating. The question of the capability of turbine blade materials to withstand the very arduous conditions arising from this cause is giving designers considerable thought. The limit of superheat at present appears to be about 800 degrees F., and this is sufficiently high to cause the question of creep to be considered. Table VIII illustrates the comparative performance under creep test of Monel and stainless iron. These results were taken on Monel in the condition resulting from silver soldering, and on stainless iron, in that resulting from brazing. It will be noted that where the total life may not exceed from 1000 to 1500 hours, both materials will operate under the same working stresses. Where the life expected is of the order of from 10,000 to 100,000 hours, Monel appears to be definitely superior. The most recent development in this field, however, has been that of the manufacture of integral root blades by a special extrusion and subsequent cold swaging process. The Author is aware that blades having a root have been made by other processes in other materials, but the process that has been applied to the Monel blades has many features that make it superior to any yet evolved.

Drop stamped blades have also been made in this form, but this method has many serious disadvantages. Briefly, the process consists of extruding a group of blades from a solid billet. The blades in the group are separated and these individual blades are then swaged on machines specially built for the purpose. Annealing takes place after each pass or alternate pass. It will be seen that the number of operations from the raw material to the finished blade is small. A feature of the method adopted to swage the blades is that blades tapered from root to tip can be made with equal ease, utilizing the same tools as for parallel blades. Further, the macrograph in Figure 3 illustrates that the transformation from the thick root into the thinner blade is accomplished in such a way that there is no serious disturbance of the flow lines of the material, such as may be expected from gap rolling or drop forging. The shape of the blade at the point of transformation is such that stress concentration there is avoided. It will also be appreciated that no brazing or building up of sections is necessary, and altogether, a turbine bladed in this fashion is bound to be superior to one where brazing has been employed, and the designer can employ higher stresses and higher rotor speeds, thus reducing space and weight. The process outlined above was designed for fabricating blades from high nickel alloys only, and cannot be applied to other materials. Blades have already been successfully produced by this method in "K" Monel.

As explained earlier, ordinary Monel is suitable for all but the most severe forms of blade erosion. Turbine builders are well aware that in impulse turbines the blasting action of the steam is very severe. Generally, for impulse rows a 30 per cent nickel-chromium steel is employed, and integral root blades of this material are usually machined from the solid bar with considerable expense and difficulty. For erosion resistance, a considerable degree of surface hardness, coupled with intrinsic toughness, is required. Ordinary Monel does not lend itself to a high degree of hardness, the normal figures being in the region of 200 Brinell. "K" Monel, however, offers a positive solution of this problem. It can be extruded and swaged with the same ease as Monel, and since it can be heat treated, the degree of hardness can be varied by modifying the thermal treatment already described, up to a maximum of 320 Brinell. This alloy is equally suitable for the manufacture of strip blading, the thermal hardening being carried out on the blading material before cutting.

Tubes. The most familiar tube for marine engineering is the condenser tube. The troubles experienced with brass condenser tubes is well known. With a view to avoiding these troubles, tubes from a number of alloys have

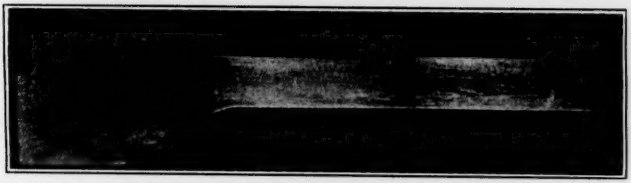


FIGURE 3.

been employed. Of these, probably the best known and most universally applied is the 70-30 cupro-nickel tube, and since this material falls within the range of alloys under review, it is proposed to give a short sketch of its development. Cupro-nickel tubes were first marketed in 1922 and then only in the 80-15 and 80-20 alloys. In these early days great difficulty was experienced in casting the metal and fabricating the tubes. Steady experimentation in adding nickel to the alloy and reducing the copper have resulted in the 70-30 alloy so familiar and so largely applied today for this purpose. It is well known that resistance to corrosion in condenser tubes is largely due to the formation of a protective film on the surface of the material. The nickel present in this alloy is particularly effective in assisting the formation of this film and in promoting healing of the film when it has been damaged. It was found that, as the nickel content increased, better results were obtained in service. Experiments to determine whether increasing the nickel content to a greater degree than 30 per cent would continue the improvement, have shown no advantage. It has, in fact, been demonstrated that an increase of the nickel content above 50 per cent results in tubes made from it having a lower performance than the 70-30 alloy. Examination of this is, however, still in progress, especially in America.

The development of this alloy has been long and thorough, and the stage has now been reached when it would appear that little is left to be done in improving casting technique or the quality of finish of the tubes. Future improvements in the material will probably take the form of slight additions of other alloying elements to meet the more severe conditions arising from the increased water speeds and temperature fluctuations likely to be experienced. Improvements in the tubes will consist principally of exploiting new methods designed to produce a super finish more economically. It will be worth while, therefore, reviewing the progress that is being made in the manufacturing methods of condenser tubes.

The early tubes were generally made from hollow cast billets which were subsequently turned all over the outside and bored out to remove all defects accruing from casting. The hollow shells of thick walls thus obtained were then laboriously cold drawn to the finished size. Annealing between draws was usually accomplished in muffle furnaces which allowed the metal to scale, since the annealing temperature is in the region of 820 degrees C. In order to remove this scale, heavy pickling was necessary, resulting in etching of the tubes and much loss of valuable metal. Subsequent improvements in casting technique made it possible to pierce solid billets by machines of the Stiefel type. By this process, hollow shells were made of small diameter and thinner walls than was possible by the casting method, and the necessity of preparing special cores was dispensed with, as was also the boring of the hollow casting. The billets had still to be turned on the outside before piercing. The same methods of drawing, annealing and pickling the tubes had still to be used, although the number of draws and annealing was materially reduced.

The next advance was two-fold. Extrusion at relatively low temperature had been employed in the manufacture of brass tubes for many years, but due to the absence of suitable tool steels capable of withstanding the higher temperatures and pressures necessary to extrude this material this method could not be utilized. Thanks to the advent of the tungsten-chromium hot-working steels, it was at last possible commercially to extrude the 70-30 alloy. In the beginning, the billets were about 3½ inches in diameter by 7 inches in length, and they had to be drilled before extrusion, as it was not possible to pierce the hole in the billet with the mandril material available. The general progress of these hot-working methods has been in the direction of producing, by a hot operation, a tube as near to the finished size as possible,

in order to cut down the amount of cold drawing and annealing. Mandrils were generally about 1 inch in diameter, and the hot extruded tubes were therefore about 1 inch in the bore and had a wall thickness of approximately ⅛ inch, the length of the tubes varying from 6 to 12 feet, according to the length of billet employed. Billets had still to be turned on the outside to remove casting defects, consisting of surface and subcutaneous troubles often originating from the metal moulds or the method of pouring the metal. Another feature which made it essential to drill the billets was the necessity of preserving extreme accuracy in concentricity, for when it is drawn on a bench any pronounced eccentricity in the extruded tube persists right to the finished tube. Improved press design, however, has latterly made it possible to pierce and extrude billets of 70-30 cupro-nickel into excellent tubes, although in order to preserve concentricity and give strength to the mandrils, there is a general tendency to extrude tubes of greater diameter, leaving more cold work to be done, on the ground that larger mandrils have a much longer life and maintain a higher degree of accuracy of concentricity, due to their stiffness, than those of smaller diameter. Further because of the saving of drilling time and increased yield, there is sufficient margin substantially to cover the expense of the extra cold passes involved. An interesting development is at present in process in the preparation of billets for tube extrusion. It has been explained that when extruding tubes of small diameter, it is necessary to drill the billets. It has been found that an alternative to this is to extrude hollow bars on the 2500-ton press. These bars are of the diameter and bore of the billets required for the smaller presses. Billets of suitable length are then cut from these bars, thus obtaining a pierced billet without the necessity of drilling, and with the consequent saving in material. The application of this double-extrusion method to nickel alloys is still in its infancy, but the results so far are promising.

Extrusion presses for the production of these tubes are of two types, namely, horizontal and vertical, and a great deal of controversy exists as to which type produces the most concentric tube. The Author's opinion is that tubes should always be extruded on a vertical press, as experience has shown

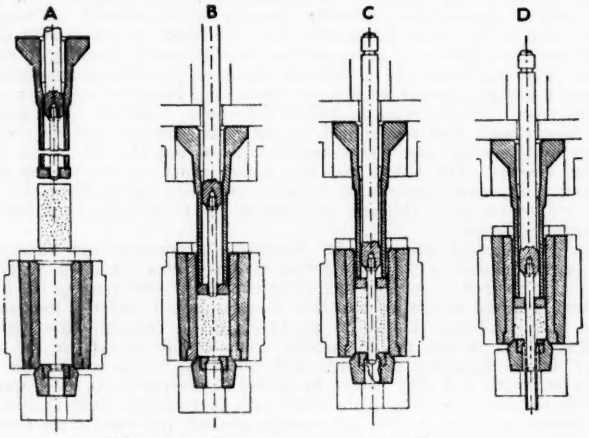


FIGURE 4.—EXTRUSION CYCLE FOR TUBES.

that there is a tendency for the billet to center itself more accurately in the container, especially where dies having a conical entrance are employed, as is generally done with hard alloys of this type. Further, a smaller clearance is possible when inserting the billet vertically. With the horizontal press, the tendency is towards encouraging eccentricity due to the billet always lying on the bottom of the container. Since the billet has always a fair amount of clearance to allow it to be pushed easily into the container, it obviously takes up a position relative to the piercer which is already eccentric to the container. Compression of the billet is, of course, employed to overcome this by making the billet fill the clearance space, but if this is done perfectly, piercing becomes much more difficult owing to friction on the container walls. It therefore appears that the vertical press should be used until the size of tube required becomes too great for the capacity of the vertical presses available. Figure 4 shows the extrusion cycle for a modern vertical press and is self-explanatory. The vertical press has been very successful in extruding tubes from drilled billets.

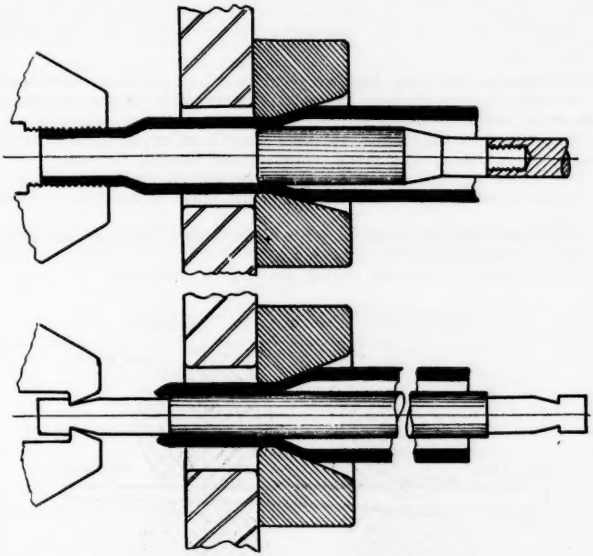


FIGURE 5.—SET-UP OF TOOLS FOR TUBE DRAWING.

Almost contemporaneously with the application of extrusion came the urge to improve methods of annealing between cold draws, so as to eliminate pickling if possible. Advances in the design of the electric annealing furnace supplied the answer to this requirement, but only to the extent of freeing the tubes from the effects of the gases inherent in the products of combustion in gas- and oil-fired furnaces. Annealed material was still subject to oxidation from the oxygen in the furnace, although this was greatly minimized, and so the controlled atmosphere, or bright annealing furnace, was evolved. One

of the latest furnaces for annealing tubes of this type is one in which the furnace atmosphere is derived from anhydrous ammonia cracked by being passed over a suitable catalyst at a carefully controlled temperature. The gas produced in this way contains approximately 75 per cent hydrogen and 25 per cent nitrogen. It is a highly reducing gas, and the result is that tubes annealed in this type of furnace, employing this atmosphere, come out perfectly bright. Pickling is only necessary now with the extruded tube.

Methods of drawing the tubes then began to receive attention. Drawing on draw benches, employing tools set up as shown in Figure 5, has for generations been the recognized method of making tubes. An American one day set out to devise a machine for producing tapered golf shafts, and after he had set the machine going on a shaft, left it to attend to something else. When he returned he was astonished to find his gear had produced a parallel tube. What had happened was that the machine did produce a tapered tube from the parallel tube he originally started with, but due to continuing to work after the whole tube had been completely tapered, the machine began to produce another parallel tube, but of smaller diameter and thinner wall than the original. That, in short, was the inception of the idea for what is now generally known as the "tube-reducing machine." The advantages of this process are:

1. Whereas on the draw benches from 20 to 25 per cent reductions per pass are the rule, this machine in one pass can make a 70 per cent reduction on the cross section of the tube.
2. No pointing of the form shown in Figure 5, as required for draw-bench methods, is necessary, thus saving material and time.
3. Due to the amount of work that can be put on the tubes at one time, the number of annealings is cut down and the finish of the tube is therefore improved.
4. Two operatives are required for a draw bench, but one man can look after two or even three of these machines.
5. The tendency for scoring during drawing is eliminated.

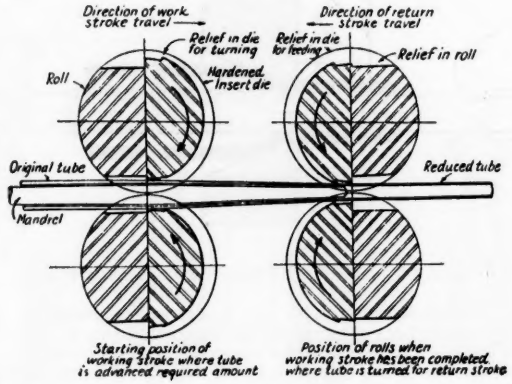

Direction of work stroke travel
Direction of return stroke travel
Relief in die for turning
Relief in die for feeding
Relief in roll
Roll
Hardened insert die
Original tube
Reduced tube
Mandrel
Starting position of working stroke where tube is advanced required amount
Position of rolls when working stroke has been completed, where tube is turned for return stroke

FIGURE 6.—POSITION OF REDUCING ROLLS BEFORE AND AFTER WORKING STROKE.

The principle of the tube-reducing machine is illustrated in Figure 6. The essential working parts are a tapered mandril and two rolls having eccentric grooves of varying cross section along the length of these grooves. In appearance, the roll housing is very similar to that for an ordinary rolling mill, with the exception that it is not fixed to the bedplate, but is free to reciprocate. The rolls, however, do not rotate, nor are they driven as in a rolling mill.

Owing to the conformation of the grooves in the rolls, it is only necessary for them to make a partial revolution at each stroke, and the length of the periphery of the roll in contact with the tube is governed by the travel of the roll housing. The roll spindles are, of course, coupled together by spur gears in order to keep the calibers of the two rolls in register, and heavy connecting rods coupled to a crank transmit the reciprocating action to the roll housing. It may be confusing to understand why, since the calibers are not revolving, it should be that these parts are made in the form of rolls. Reference to Figure 6 will show that this is a very convenient way of obtaining a strong construction, which is of extreme importance and also economical. The dies are made of very special material and can be applied to these rolls in the form of inserts, and as the whole strength of the roll is supporting this insert, its size can be considerably reduced. Further, as provision must be made for changing the size of the grooves in the rolls to suit varying sizes of tube, these inserted dies meet this requirement very effectively, since without this arrangement, it would be necessary to withdraw the roll spindles and change the rolls every time a change of the size of tube had to be made or a roll groove had worn so that it required reconditioning. It should also be noted that as the calibers wear, packing can be inserted behind the inserts to compensate for this.

TABLE IX.

PRODUCTION OF MONEL WALL TUBE OF 1 INCH OUTSIDE DIAMETER BY 0.065 INCH, EXTRUDED TUBE STOCK OF 2¼ INCHES OUTSIDE DIAMETER BY ¼ INCH.

	Number of Operations	*Outside Diameter of Tube in.*	*Wall Thickness in.*	*Reduction per Pass per cent*	*Total Reduction per cent*
Draw Bench:	—	2.25	0.25	—	—
	1	2	0.205	27	—
	2	1.75	0.175	25.7	—
	3	1.55	0.135	30.7	—
	4	1.35	0.105	32.7	—
	5	1.163	0.08	32.2	—
	—	1	0.065	31.2	88
Tube-Reducing Machine:					
	—	2.25	0.25	—	—
	1	1.25	0.095	78	—
	2	1	0.065	44	88

The operation of the machine is briefly as follows. The tube stock to be reduced is slid over the tapered mandril and mandril rod. At the end farthest away from the roll housing it is clamped in a collet. This collet is free to rotate along with the mandril bar within the tube. By this means, after each traversal of the roll caliber on the tube, a partial rotation of the tube and mandril is made so as to present a new surface to be operated on. This ensures the production of a round tube and keeps the tapered mandril from developing flats. As the swaging operation proceeds, the tube stock is fed

slowly forward into the rolls, the feed being determined by the amount of metal which the rolls can conveniently roll off at each traversal. This type of machine is now being employed on the production of tubes in all the nickel alloys already referred to. Table IX shows the reductions obtainable by this method over those by ordinary draw-bench methods. A great number of 70-30 cupro-nickel tubes are now being produced by this method in this country, America and Germany. The pursuit after further improvement still continues, and in Germany a process has recently been developed and patented which claims to be even superior to the tube-reducing machine, but this yet remains to be seen.

Mention was made earlier of the severe duties to which condenser tubes are subject, and the possibility of these becoming even more arduous. In this connection, reference was made to the new alloy recently developed, called "Inconel." It is too early yet to say just what part this alloy is destined to play in the condenser tube field, but once certain difficulties in the production of tubes from this material have been surmounted, as they certainly will be, the Author is of opinion that as a super condenser tube material it has distinct possibilities.

In concluding this survey, it will probably be a source of satisfaction to Scottish engineers and shipbuilders that such a large amount of the work in connection with the developments referred to has been carried out in Scotland.

THE FLOW OF COMPRESSIBLE GAS.

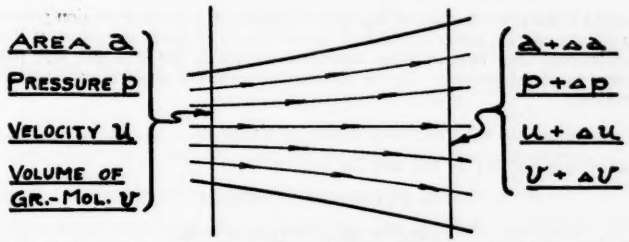
The following article by B. V. Korvin-Kroukovsky, of the Edo Aircraft Corporation, was published in the Journal of the Franklin Institute of the State of Pennsylvania, January, 1939. It is of timely interest in view of doubts expressed relative to the test dive speed of 575 miles per hour reported to have been made by a Hawk 75A pursuit plane in January, 1939, at Buffalo, N. Y. "Shock waves" or "compression shock" are expected to retard an air plane at some lesser speed. The air plane in question was one of 100 being built for the French Government. The speed was recorded on a French instrument which was checked before and after the flight. The company had no comment other than that the values reported were obtained from a French recording instrument.

The relations are derived between velocity, density and pressure in a flowing compressible gas on the basis of fundamental mechanical principles of the conservation of matter, of momentum and of energy. The results are checked by application to test data on the discharge of superheated steam, and are found to be in excellent agreement throughout the range of pressure ratios from 1.00 to 0.20. It is shown that below certain (critical) pressure ratio the polyatomic gas behaves as monatomic one, indicating that energy transfer ceased between rotational and translational motions of molecules. This phenomenon occurs apparently only in accelerating flow, and the change from acceleration to deceleration liberates the temporarily unavailable energy of rotation, and precipitates the sudden increase of pressure, known as "Compression Shock" in aerodynamics.

In his previous work[1] the author considered the particular case of the flow of compressible gas, that of the efflux from the orifices. The principles of the kinetic theory of gases in regards to the conservation, and to the equipartition of the molecular energy, were used in the derivation of the expressions for the velocity, density and discharge of compressible gas, and these expressions

were found to be in good accord with the experimental data. The use was made of the empirical coefficient K, representing the ratio of the momentum of the jet to the product of the orifice area and the differential pressure. The use of this coefficient simplified the solution of this particular problem of the efflux of gas from an orifice, but put the results in the form awkward to extend to the more general cases of the gas flow. Moreover the employment of such an empirical coefficient disguised the effect of the fundamental properties of the compressible gas. In the present work the author develops the laws of the gas flow on basis of these fundamental properties without resorting to the empirical coefficients, and in the form which permits their general application to any range of pressure ratios, either above or below the critical one.

Figure 1 shows a length of a conduit or of a filament of the flowing gas between two transverse sections of the areas a and $a+\Delta a$. At the upstream section the gas pressure, gas velocity and the volume of a gram molecule have the values p, u and v. In transition to the downstream section all of these quantities undergo certain changes Δp, Δu and Δv. For the study of these changes three fundamental relations are available, that of the conservation of matter, of the momentum and of the energy. It is possible therefore to



A section of a conduit, or of a filament of streaming gas showing, the changes in sectional area, pressure, velocity and volume of the gram molecule.

FIGURE 1.

express any three of the above variable quantities in terms of the fourth. In aerodynamics the relation between velocity u and pressure p is of the particular interest. In case of the steady flow the mass of the gas flowing through any one transverse section of the stream is the same as that flowing through any other section. Denoting this mass by m, and the mass of a gram molecule by M, the principle of the conservation of matter can be expressed as:

$$m = Mau/v = \text{Const.}$$

The momentum is mu, and the change of the momentum:

$$d(\text{Momentum}) = m\,du = (Mau/v)\,du. \qquad (1)$$

This change of the momentum is produced by the pressure gradient acting along the stream. Considering the volume of gas shown on Figure 1, the pressure on the right-hand side, neglecting the magnitudes of second order:

$$(p+\Delta p)(a+\Delta a) = pa + a\Delta p + p\Delta a.$$

Pressure on the left-hand side:

$$-pa.$$

Component of the pressure on sides of the filament taken in the direction of the flow:

$$-(p+\Delta p/2)\Delta a = -p\Delta a$$
$$\text{Net accelerating force} = a\Delta p \qquad (2)$$

or for infinitely small increment we can substitute for the accelerating force a dp. Equating the change of momentum from Eq. (1) to the accelerating force from Eq. (2):

$$(Mau/v)\,du = -a\,dp;$$

cancelling a and transposing, we obtain the differential equation for the change of momentum:

$$-dp = (M/v)u\,du. \qquad (3)$$

The equation of energy was derived by the author in his previous work,[1] and can be represented in the form:

$$pv = RT - (M/f)u^2, \qquad (4)$$

where f is the total number of degrees of freedom of molecular motion possessing kinetic energy, taken on basis of kinetic theory of gases to consist of three translational, and two or three rotational velocities for diatomic and polyatomic gases respectively. In the differential form the above energy equation becomes:

$$p\,dv + v\,dp = -(2M/f)u\,du. \qquad (5)$$

Multiplying Eq. (3) by 2/f, and Eq. (5) by 1/v:

$$-(2/f)\,dp = (2M/vf)u\,du, \qquad (3a)$$

$$p\,dv/v + dp = -(2M/vf)u\,du. \qquad (5a)$$

Adding Eqs. (3a) and (5a):

$$p\,dv/v + (1-2/f)\,dp = 0.$$

Transposing:

$$-dv/v = (1-2/f)\,dp/p. \qquad (6)$$

Integrating between limits we obtain:

$$v_1/v_2 = (p_2/p_1)^{(1-2/f)} = \rho_2/\rho_1, \qquad (7)$$

which is the fundamental relation between the specific gravity and pressure in the stream of gas expanding without loss or gain of the total energy, so that decrease of the internal energy is equal to the increase of the kinetic energy of the streaming gas.

DENSITY AND PRESSURE IN ADIABATIC EXPANSION.

It is of interest to derive for comparison the density and pressure relations for the adiabatic expansion of gas under a piston, in which the reduction of the internal energy of the gas E_1 is equal to the external work W done on the piston:

$$E_1 + W = E_1 = \text{Const.} \qquad (8)$$

On basis of the kinetic theory of gases we can evaluate:

$$E_1 = pvf/2.$$

Referred to one gram molecule of gas the external work W is evidently:

$$W = \int_{v_1}^{v_2} p\,dv.$$

Substituting above values into Eq. (8):

$$pvf/2 + \int_{v_1}^{v_2} p\,dv = \text{Const.}$$

Differentiating:

$$(f/2)p\,dv + (f/2)v\,dp + p\,dv = o$$

and transposing:

$$-dv/v = \frac{f}{f+2}\frac{dp}{p}.$$

Integrating between limits:

$$v_1/v_2 = (p_2/p_1)^{f/(f+2)} = \rho_2/\rho_1. \qquad (9)$$

Substituting the values of $f = 6$ for steam and $f = 5$ for air we obtain the exponents of 1/1.33 and 1/1.4 familiar to students of thermodynamics.

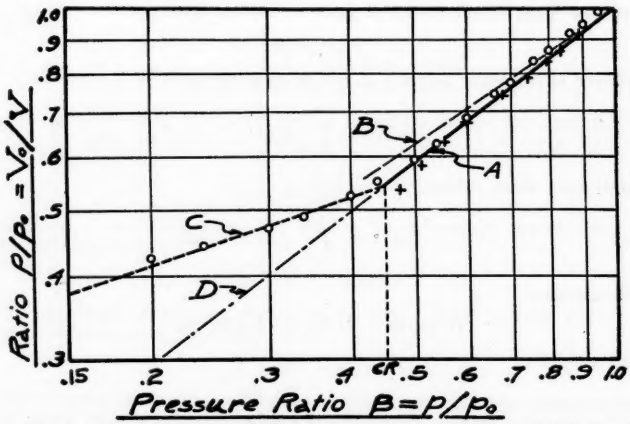
EXPERIMENTAL VERIFICATION OF THE DENSITY RATIO.

The actual density of the streaming gas can be easily determined by the analysis of the experiments on the discharge from the orifice in which both the velocity and the weight discharged were measured. The volume of the gas discharged is au, where u is the velocity and a is the jet area, equal to the orifice area in case of the orifice with rounded edges. If w is the weight discharged, the density is evidently:

$$w/au.$$

The original density of the gas at rest can be determined, of course, from the pressure and the temperature of the gas in a vessel before expansion. The calculations of the actual density ratio ρ/ρ_0 were made by the author using this method for the discharge of the superheated steam,[2, 3] and the results are plotted against pressure ratio on Figure 2. For the higher range of pressure ratios the experimental points follow closely the straight line marked A, which has the slope of 1/1.33 corresponding to Eq. (9) with $f = 6$.

The Eq. (7) used with the same value of $f = 6$ gives the curve marked B on Figure 2, which is not in as good agreement with test results as the curve A representing Eq. (9). The discrepancy between Eqs. (7) and (9) is not in the method of their derivation, but is contained in the basic energy Eq. (4). Indeed the value of v_1 and therefore the density ratios, can be computed directly by Eq. (4) substituting in it the experimental values of p and u, and the density ratios computed by this method are found to follow closely the curve B of Figure 2.



Density ratio plotted as function of the pressure ratio for superheated steam flowing through the orifice with rounded approach. Circles are from tests of Warren and Keenan,[3] and crosses from Steam Nozzle Research.[3] The change of slope between curves *A* and *C* indicates that important change takes place in the distribution of the molecular energies at (critical) pressure ratio of 0.45.

FIGURE 2.

While Eq. (9) is found to be in better agreement with experiment than Eq. (7), the latter has the advantages to be discussed later, and therefore will be retained in the remainder of this work. As a practical expedient for increase of accuracy in numerical calculations it will be assumed that f exceeds by 2 the values commonly used for gases in stationary state, i. e., is equal to 8 and 7 for the steam and air respectively, instead of theoretical value of 6 and 5. This expedient will make Eq. (7) to conform to the curve A of Figure 2.

DENSITY RATIOS FOR PRESSURE RATIOS BELOW CRITICAL.

The salient feature brought out by the plot of Figure 2 is the well defined break in the curve of density ratio vs. pressure ratio at the value of 0.45 of the latter. For the pressure ratios below 0.45 the curve assumes a new slope, indicating a probable change in the distribution of the molecular energies. The experimental data in this region are found to follow closely the curve C of the slope of 1:3, which is indicated by Eq. (7) on the condition that f assumes a new value equal to 3. Such a change in the value of f indicates that rotational velocities have ceased to take part in the interchange of energy in collisions of molecules, and that only the energy of translational motion remains available. The fact that such a change may occur in a gas is indicated by the application of quantum mechanics to the kinetic theory of gases.[5] It is shown that rotational energies which the molecule can take are restricted to a limited number of discrete values, and that certain minimum energy of translation is required in collision of two molecules in order to produce the change from one rotational energy state to another. If the energy of translation is reduced below this minimum value, the molecular collisions do not produce any further change in the rotational energies, and the gas

behaves as monatomic gas with its appropriate value of $f = 3$. The use of Eq. (7) was retained in this work because it produces the experimentally verified curve C upon substitution of $f = 3$.

It must be observed here that translational energy of the molecules of steam at the pressure ratio of 0.45 in the tests illustrated by Figure 2 exceeds by some 30 or 40 times the energy of the rotational quanta for water vapor in stationary state. Apparently in the condition of the accelerated flow from the test nozzle there are unknown factors which cause cessation of the energy transfer between translational and rotational motions of molecules at the energy level exceeding by many times the value of rotational quanta for the gas in normal state. The significance of this phenomenon will be further considered at the end of this work.

VELOCITY AND PRESSURE RELATIONS FOR PRESSURE RATIOS ABOVE CRITICAL.

Denoting by:

E_i, internal energy of gas,
E_u, kinetic energy due to streaming velocity u,

we can write for the change from the state 1 to the state 2 of the gas:

$$E_{u_2} - E_{u_1} = E_{i_1} - E_{i_2}. \tag{10}$$

The kinetic energy of streaming per gram molecule of mass M is:

$$E_u = Mu^2/2 \tag{11}$$

The internal energy of gas is:

$$E_i = fpv/2; \tag{12}$$

from Eq. (7) it follows that:

$$v_1 p_1^{(1-2/f)} = v_2 p_2^{(1-2/f)} = v_0 p_0^{(1-2/f)} \tag{13}$$

where v_0 and p_0 denote the volume of the gram molecule and the pressure of the gas at rest. Eq. (13) can be transposed as follows:

$$p_1 v_1 = p_0 v_0 (p_1/p_0)^{2/f} = RT(p_1/p_0)^{2/f}; \tag{14}$$

likewise:

$$p_2 v_2 = RT(p_2/p_0)^{2/f}. \tag{15}$$

Substituting now Eqs. (14) and (15) into Eq. (12), and then Eqs. (11) and (12) into Eq. (10):

$$M(u_2^2 - u_1^2)/2 = fRT[(p_1/p_0)^{2/f} - (p_2/p_0)^{2/f}]$$

or transposing, and substituting $R/M = gB$, where B is the gas constant for the particular gas referred to the unit of weight:

$$u_2^2 - u_1^2 = fgBT[(p_1/p_0)^{2/f} - (p_2/p_0)^{2/f}]; \tag{16}$$

for the particular case of the discharge from an orifice, where $u_1 = 0$ and $p_1 = p_0$, we have:

$$u^2 = fgBT[1 - (p/p_0)^{2/f}]. \tag{17}$$

The weight discharged from the orifice with rounded edges is evidently:

$$w = a\rho u, \tag{18}$$

where a is the area of the orifice,

u the velocity determined from Eq. (17),

ρ the density of discharged gas in gravity units. This can be obtained from Eq. (14) by substituting $v_1 = Mg/p$ and $R/M = gB$, yielding:

$$\rho = p/BT\,(p/p_0)^{2/f} \tag{19}$$

This form is convenient for use in connection with Eq. (17), as both include the same function $(p/p_0)^{2/f}$.

PRESSURE RATIOS BELOW CRITICAL.

When the state 2 of the expanding gas involves the pressure ratio below critical, the pressure-density relation is not a continuous function, but is represented by the broken line A and C on Figure 2. Therefore Eqs. (10), (11) and (12) for the internal energy will take the form:

$$E_{i_1} - E_{i_2} = f(p_1v_1 - p_cv_c)/2 + 3(p_cv_c - p_2v_2)/2, \tag{20}$$

where p_c and v_c denote the pressure and the volume of the gram molecule of gas at critical pressure. The value of $f = 3$ is substituted for the pressures below critical, as this corresponds to three degrees of molecular freedom in translation, representing the constant universal for all gases. For p_1v_1 we can substitute Eq. (14), and the expression for p_cv_c takes the same form. For p_2v_2 we can substitute on basis of Eq. (15) with $f = 3$:

$$p_2v_2 = p_cv_c(p_2/p_c)^{2/3} = RT\,(p_c/p_0)^{2/f}(p_2/p_c)^{2/3}; \tag{21}$$

making these substitutions in Eq. (20) we get:

$$E_{i_1} - E_{i_2} = fRT[(p_1/p_0)^{2/f} - (p_c/p_0)^{2/f}]/2 + 3RT[(p_c/p_0)^{2/f} - (p_c/p_0)^{2/f}(p_2/p_c)^{2/3}]/2.$$

Equating the change of internal energy to the change of kinetic energy, transposing and letting $R/M = gB$, we get the final expression for the change of velocity with the change in pressure:

$$u_2^2 - u_1^2 = fgBT[(p_1/p_0)^{2/f} - (p_c/p_0)^{2/f}] + 3gBT\,(p_c/p_0)^{2/f}\,[1 - (p_2/p_c)^{2/3}]; \tag{22}$$

for the particular case of the discharge from the orifice, substituting $u_2 = u$, $p_1 = p_0$, and $p_2 = p$ we have:

$$u^2 = u_c^2 + 3g\,BT\,(p_c/p_0)^{2/f}\,[I - (p_2/p_c)^{2/3}], \tag{23}$$

where u_c is the velocity of discharge at critical pressure determined by Eq. (17) substituting u_c for u, and p_c for p.

The weight of the gas discharged can be again computed by Eq. (18), but the density in this case is determined by the use of Eq. (21) and becomes:

$$p_c = \frac{I}{BT}\;\frac{p_2}{(p_c/p_0)^{2/f}\,(p_2/p_c)^{2/3}}. \tag{24}$$

The subscript c is added in order to distinguish the density as given by Eq. (24) from that of Eq. (19) and in order to emphasize that it refers to the point on the curve C of Figure 2.

THE CHECK OF FORMULAE.

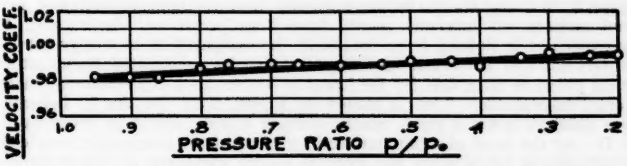
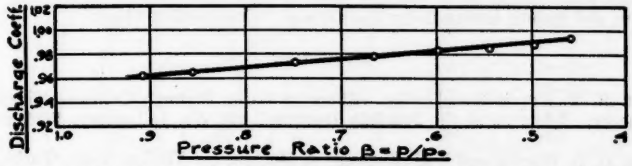
The experimental data are not available to check the general Eqs. (16) and (22), but tests on the efflux of gas from an orifice are available for steam and for air, and can be used to check the Eqs. (17) and (23). The tests made with superheated steam [2] are particularly valuable as they included the determination of steam velocity for the pressure ratios as low as 0.20. Figure 3 shows the velocity coefficient defined as the ratio of the experimental to the calculated velocity. The velocity was calculated by Eqs. (17) and (23) using the value of $f = 8$, as this was explained already when discussing the verification of Eq. (7). The value of B for the superheated steam was taken as 85 in Lbs.-Cu. Ft.-Degrees F. units, the value which was found to check well with Peabody's Steam Tables.[6] The curve of Figure 3 shows the excellent agreement of test results with the experimental data, particularly considering the wide range of the pressure ratios

Velocity coefficients for the discharge of superheated steam through the orifice with rounded approach for wide range of pressure ratios.

FIGURE 3.

covered. The velocity coefficient gradually grows from 98.2 per cent at $p/p_0 = 0.95$ to 99.4 per cent at $p/p_0 = 0.20$.

The experimental data on the discharge of air [4] covered only the pressure ratios above critical, and did not include the measurements of velocity, but only of the weight of the air discharged. The coefficients of discharge plotted



Discharge coefficients for the air flowing through the orifice one inch in diameter with rounded edges.

FIGURE 4.

on Figure 4 were computed from these data by the use of Eqs. (17), (18) and (19) with the value of $B = 53.34$, and $f = 7$. The agreement of the calculations with test results is again satisfactory, and the general trend is again towards increase of the coefficient with the increase of the Reynolds' Number, which is in accord with the experimental investigation of the flow of liquid through standard nozzles.[7]

DIVERGING FLOW.

The application of Eqs. (17) and (23) to the discharge of steam from the orifice with rounded approach provided the experimental verification for the particular case of the converging flow in the direction of the falling pressure gradient. This can be considered as reasonable verification of more general Eqs. (16) and (22) for such a flow. The data are not available for the checking of these expressions for the case of the divergent flow, or the flow with negative acceleration against rising pressure gradient. For the flow above the critical pressure ratio there is no reason to doubt that Eqs. (16) and (17) will apply, as there are no changes in the properties of the gas which affect the distribution of molecular energies.

For the pressure ratios below critical the situation is entirely different. Below this pressure ratio the gas acquired new properties which may modify its further behavior. Were the gas made to expand relatively slowly under a piston, the ratio of specific volumes would have followed the line D of Figure 2, and the equipartition of energy between translational and rotational motions of molecules would have been preserved. In case of the free expansion in flowing from the orifice the equipartition of energy between translational and rotational motions of molecules apparently ceases at the critical pressure ratio, and for the lower pressure ratios the rotational energy becomes unavailable. This is shown on Figure 2 by the line C indicating lower pressure p for a given specific volume V than would be given by the line D. At the point of minimum sectional area of the convergent nozzle the gas contains in latent form the internal energy measured by the horizontal distance between the curves C and D for any specific volume V.

It is not known what the mechanism is that causes the cessation of the energy transfer between rotational and translational motions of molecules at critical pressure ratio, and at the energy level corresponding to many times the lowest rotational quanta for the gas in normal state. It appears, however, that it is connected with the case of accelerated flow and falling pressure gradient. The change from acceleration to deceleration apparently restores the equipartition of molecular energies, thereby liberating the heretofore unavilable energy of rotation, and precipitating the sudden increase of the pressure. Such a sudden increase of the pressure was observed in high speed wind tunnels at or past the point of maximum constriction of the air flow, and became known under the name of "Compression Shock."

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TWO SPEEDS WITH ONE MOTOR.

Gordon Fox of the Freyn Engineering Company shows in this article how multi-speed A.C. motors operate and where they can be used. The extract is from Power, New York, N. Y., March, 1939.

If a squirrel-cage induction motor is operated on a fixed-frequency circuit, its synchronous speed can be changed only by changing the number of poles in the stator winding. This can be done by using two or more separate stator windings, each connected for a different number of poles, or by using a single winding, so connected that it can be arranged to form different numbers of poles. Theoretically, any number of speeds are possible, but practically, four synchronous speeds are maximum for squirrel-cage motors and two for wound-rotor motors.

Two synchronous speeds, 2-to-1 ratio, can be obtained by simple reconnection of one set of stator windings, as in Figures 1 and 2. In Figure 1 the two coils of a phase winding are connected normally to produce a north and a south pole, but in Figure 2, one coil is reversed to obtain two north poles. This arrangement causes the magnetic flux to flow as indicated, creating two south poles, termed consequent poles, between the two north poles.

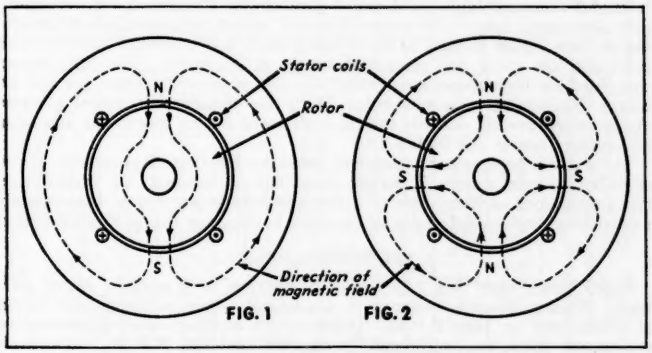


Fig. 1—Schematic diagram of motor having two poles with normal connection of coils. Fig. 2—Same as Fig. 1, except coils are connected to give four poles, by reversing current in one coil

A special winding is used with coils having a throw which has short pitch for the smaller number of poles and over pitch for the larger number. High speed on one type of motor is obtained with the motor connected 2-parallel-

star. For low speed, the winding circuits are rearranged in series star so that all pole-phase groups have like polarity. An equivalent number of consequent poles of opposite polarity then occur at intermediate points. This results in twice the number of poles of half the arc. Speed of rotation of the magnetic field is halved, reducing synchronous speed accordingly. When rotation of the magnetic field is halved, rate of flux change is proportionately decreased and twice the coil turns are required in series, for the low speed, to produce proper counter-voltage. Changes in the connections are made by bringing out the coil ends and completing the connections for either arrangement in the controller.

HIGH TORQUE.

For these connections, total flux, and the resulting torque capacity, are 50 to 100 per cent greater at high speed with the normal connection and fewer poles. Because of this relatively high-torque capacity at high speed, a motor having 2-parallel-star connection has three or more times the horsepower capacity at high speed than it has at low speed. This relatively high rating at high speed is permissible because of improved ventilation at such speed. Characteristics of a motor of this type are shown in Figure 3. Such motors are used to drive machines which impose much heavier loads at high than at low speed. Centrifugal pumps and fans, and oil-well machinery fall into this category.

Frequently, a 2-parallel-star connection is used for normal high-speed duty and a single-delta connection for consequent-pole, low-speed duty. This is equivalent to impressing a relatively higher voltage upon the winding connected for low speed. Result is increase of flux and torque. Thus, torque developed at low speed is made approximately equal to that at high-speed. Figure 4 shows characteristics of a motor having this combination of connections. These motors are given a constant-torque rating, horsepower capacity at high speed being twice that at low speed.

For some designs of 2-speed motors, a single-series delta-connected winding is used for normal high speed and 2-parallel-star connection for consequent-pole slow-speed duty. This connection is, in effect, the equivalent of impressing an even higher voltage on the winding when it is connected for consequent poles and low speed, and gives high torque at low speed. The delta connection, used for high speed, has a relatively low impressed voltage per coil and torque developed is only moderate. With this combination, torque produced at low speed greatly exceeds that at high speed. This motor has a constant horsepower rating, see Figure 5.

For a given horsepower rating and speed combination, physical size of constant-horsepower motors is larger than that of constant- or varied-torque types mentioned earlier. Size of a constant-horsepower motor is comparable to that of a single-speed motor of the same horsepower rating at lowest speed.

TWO-WINDING MOTORS.

Speed ratios other than 2 to 1 must be obtained with separate stator windings. Thus, a 60-cycle motor with 6-pole and 4-pole windings will operate at either 1200 or 1800 R.P.M. If these two windings are reconnected for consequent poles, two additional speeds, 600 and 900 R.P.M., respectively, are possible. Where separate windings are employed, the higher-speed winding is usually in the bottom of deep slots and the lower-speed winding nearest the air gap. This arrangement is preferable because of lower reactance next to the air gap, a prerequisite of good design for low speeds. Each winding can be designed to give the rating and performance desired at its corresponding speed. The characteristics of 2-winding multi-speed motors are shown in Figures 6 and 7.

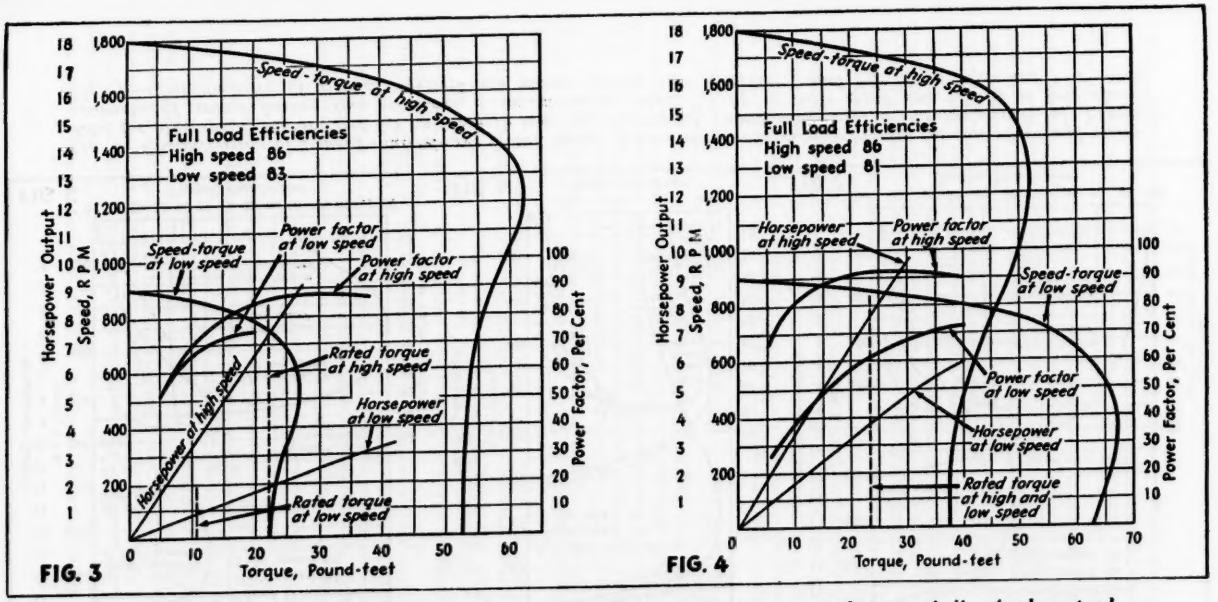


Fig. 3—Characteristics of multi-speed squirrel-cage motor having series-star-connected stator winding for low speed at low torque and connected 2-parallel-star for high speed and high torque. Motor rated 7.5 hp at high speed and 1 hp at low speed. Fig. 4—Characteristic of 2-speed squirrel-cage motor connected series-delta for low speed and 2-parallel-star for high speed, for constant torque. Motor rated 7.5 hp at high speed and 3.75 hp at low speed

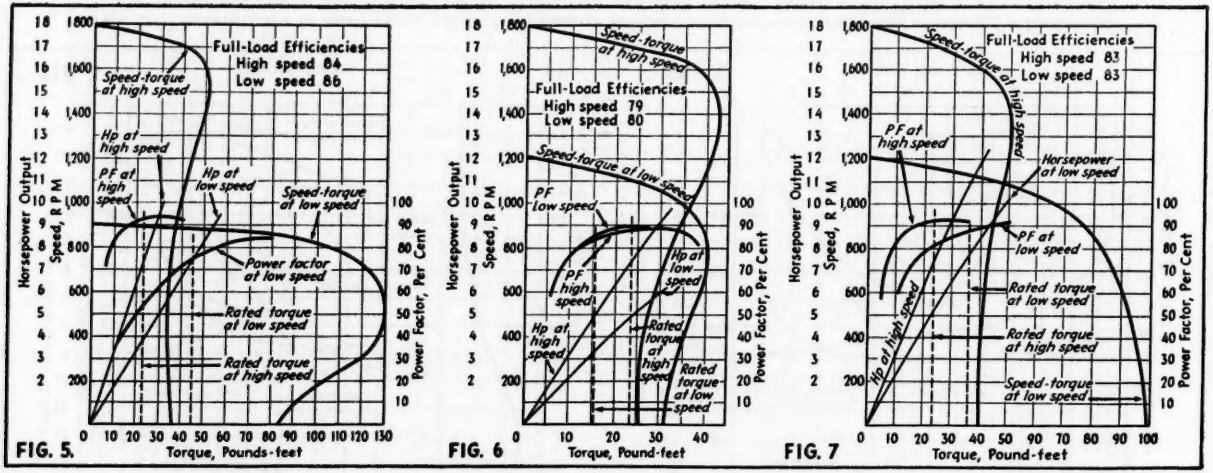


Fig. 5—Characteristics of 2-speed squirrel-cage motor having 2-parallel-star-connected windings for low speed and series-delta for high speed. Motor rated 7.5 hp for both low- and high-speed connections. Fig. 6—Characteristics of 2-speed squirrel-cage motor having two windings. Constant-torque rated, 7.5 hp at high speed and 3.5 hp at low speed. Fig. 7—Characteristics of 2-speed squirrel-cage motor having two windings, rated 7.5 hp at high and low speed

Most multi-speed motors have squirrel-cage rotors, which can be adapted for any number of poles, whereas secondary windings of wound-rotor motors must be reconnected, for different speeds, to have the same number of poles as the stator.

The controller of a 2-to1-ratio squirrel-cage motor is not complicated; only 6 leads are brought out from a 3-phase motor of this type. Two speeds from separate windings also require 6 leads between motor and controller. Four speeds from 2 windings require 12 leads between motor and controller. Wound-rotor motors demand twice as many leads, slip rings and brushes since rotor windings ordinarily must be reconnected, and are not regularly built for more than two synchronous speeds.

Multi-speed motors are ordinarily built for 3-phase circuits only. For 2-phase circuits, Scott-connected transformers change to 3-phase, because controllers for 2-phase motors would be complicated and expensive.

In single-winding multi-speed motors, changes from one speed to another are obtainable only by opening the primary circuit and then closing it with different connections. This necessary interruption of power supply is an undesirable feature of this type of motor. When two separate windings are used, it is possible in some cases to connect the second winding to the line an instant before the first is disconnected. This arrangement, which never leaves the motor without torque, is employed in connection with some elevator motors.

Multi-speed motors are not in reality adjustable-speed machines, since only a limited number of speeds can be obtained. In the great majority of applications, only two speeds are possible. At each setting, the motor operates essentially as a simple induction motor, having squirrel-cage constant-speed or wound-rotor varying-speed characteristics, according to type. Since most multi-speed motors are of the squirrel-cage design, they offer two, three or four widely differing but approximately constant speeds. Torque capacity with each connection is subject to control in design as previously described. Selection of the proper combination for a given application is dependent upon load characteristics.

Efficiency of multi-speed motors is quite high, being but slightly inferior to that of the simple induction motor and usually a little better at high speed. Power factor of multi-speed motors is likely to be rather low, particularly at lower speeds. Deep slots required to carry the double windings contribute to this fault. Large squirrel-cage multi-speed motors may require a compensator for starting.

Multi-speed motors find a limited field of application—for example, where two or three fixed speeds will suffice, particularly where an approximately constant-torque characteristic applies. Relatively low cost and simplicity of these motors encourages their use, where applicable, in preference to adjustable-speed direct-current motors or brush-shifting A.C. motors.

APPLICATIONS.

Multi-speed motors are frequently used to drive equipment such as ventilating fans, which require different speeds at different seasons or during day and night. They are sometimes used for elevator service, rotary car dumpers, or for similar duty where it is desired to accelerate gradually or to slow down and stop accurately loads of considerable inertia. For such applications, the fast speed is the normal running condition, the slow speed being used during acceleration and slow-down.

Multi-speed motors are also used where driven equipment has two distinct purposes requiring different speeds, as for example, oil-well drives in pumping and in servicing the well; to drive machinery having a range of work or

of output, as multiple-drill presses, in order to accommodate various drill sizes; and for some centrifugal driers. These are operated first at low speed until the major part of the liquid is thrown off, then at high speed for finishing the process. Another application is for sewage-pumping stations to adjust for storm conditions or perhaps high-tide.

Synchronous motors are also built in 2-speed designs for various applications.

INVISIBLE GLASS.

Reprinted from The Technology Review, Massachusetts Institute of Technology, Cambridge, Mass., January, 1939.

This article is presented as a companion to the next following article entitled Glareless Glass.

Much publicity has been given to "glareless" or "invisible" glass. Research workers at the Massachusetts Institute of Technology and at the General Electric Research Laboratory announced the achievement at about the same time. The former obtained the result by evaporating thin films of fluorine compounds on glass surfaces; the latter by coating glass with a thin film of insoluble soap. Innumerable uses can be made of such coated glass, provided a sufficiently durable film can be established. Beyond this the possibility of controlling molecular arrangement by film deposition offers a development aspect of unlimited scope.

Under a bell jar, evacuated to a millionth part of an atmosphere, a fine wire strung between contacts glows red hot, white hot. The midsection is twisted into a little cup, in which a pinch of white powder rests. It may be sodium fluoride or lithium fluoride or cryolite or another mineral of a rather large group. Clipped in strategic positions to a frame within the bell jar are strips of glass. Unseen, the molecules of the melting powder speed through the vacuum, evaporated, and are laid down in an imperceptible, transparent film upon the strips of glass. The thickness of the precipitated layer is controlled within extremely delicate limits by conditions maintained inside the bell jar and by the time of precipitation allowed.

Remove the strips of glass after treatment and they seem little changed, except that they are more difficult to see. A strange change, however, has occurred in what they do. Whereas before treatment each surface of the glass reflected four per cent of the light which struck it, so that only 92 per cent was transmitted, the glass which has been given a fine skin of sodium fluoride—a skin only a quarter of a wavelength of green light in optical thickness (a geometrical thickness of about four-millionths of an inch)—transmits 99.6 per cent of the light striking it. Such glass is, to all intents, invisible, for it casts back into the observer's eyes practically no reflection. Another strip, similarly treated but with a different precipitant, such as stibnite, is altered equally in the opposite direction; its powers of reflection are tremendously increased and in addition may be made selective, so that it reflects light of a certain wavelength only, transmitting other wavelengths. Thus red passes through it and green is reflected from it.

The principle involved in the elimination of reflection is that the refractive index—or measure of reflecting power—of the film can be made intermediate between that of air and glass. The reflections from the two interfaces are then of equal amplitude, and when the optical thickness of the film is one quarter of the wavelength of light, the two amplitudes cancel each other. The light that would normally be reflected is added to the transmitted light.

The refractive index of ordinary glass is 1.50, so the refractive index of the film should be about 1.25. This is lower than that of any fluoride crystals,

but when a fluoride crystal is deposited by evaporation, the resulting film has a lower index of refraction than that of the crystal. For example, crystalline sodium fluoride has an index of refraction of 1.33. The films evaporated in high vacuum have an index of about 1.28. If the evaporation is carried out with air present, the index of refraction of the evaporated film can be arbitrarily lowered by choosing the appropriate air pressure.

The thickness of the layer of sodium fluoride deposited determines the amount of decrease of reflection attained. Decrease of reflection, of course, means increase of transmission, and for some of the possible uses of the glass this increase is the important thing. For other possible uses, however, decrease of reflection—the negative side of the picture—is the end sought. The number of materials that can be deposited by evaporation is very great, and many of these materials have the desirable hardness and insolubility, as well as the desirable optical characteristics.

In optical equipment, for example, for applications in which the films now secured are of sufficient durability, the flare of lenses—that is, the creation of false images because of reflection—may well be eliminated by the treated glass. Flare decreases as the square of the reflecting power, so that a loss of ten points in reflection cuts down flare by one hundred. The practical utility of the reduction of flare is suggested by the fact that in lenses used by military aviators flare has been found to make accuracy in night bombing extremely difficult to secure.

In the fine arts, use of the "100 per cent" glass instead of ordinary glass for covering paintings will eliminate once and for all the annoying reflections that often stand between the observer and the picture he has traveled far to see. The curving glass display windows now installed by some stores, which depend upon curved surface to shoot their reflections into absorbing wells, may in due course be replaced by flat sheets of the treated glass, once means have been perfected for putting a tough skin of molecules over the flaky film which cancels reflection.

Another application at first thought far more remote than these, yet actually of possibly far greater significance, is in devices designed to receive solar energy to be converted into useful power. Here the old principle of the greenhouse comes into play. If sunlight strikes the new glass, it may be transmitted with 100 per cent efficiency into an insulated area. Some of the light waves themselves may be reflected from the receiver back through the glass; but the light that has been transformed into useful heat—long-wave radiation—cannot thus go back, since glass is opaque to waves of such length. The new glass therefore is of pronounced importance, inasmuch as it permits the trapping of all the sunlight reaching a given area, none being lost by reflection.

This interesting new development has been under way in the laboratories of the Institute's Department of Physics for some months. C. Hawley Cartwright and Arthur F. Turner, '29, instructors in that Department, have been carrying on the work with the aid of the color analyzer built by Professor Arthur C. Hardy, '18.

GLARELESS GLASS.

Reported by Guy Bartlett and Phillips C. Caldwell in the General Electric Review, Schenectady, N. Y., February, 1939.

A piece of clean glass transmits 92 per cent of the light; the same glass if coated with a surface film is transparent to 99.2 per cent of the light, it has been found by Dr. Katharine B. Blodgett of the General Electric Research

Laboratory. All that is necessary is that the coating be a special, extremely thin, film—a film whose thickness is measured in terms of layers of molecules—of millionths of an inch.

Fully as startling as its transparency is the way in which glass so treated does not reflect light; it is glareless. A store window so treated would not serve as a mirror for passers-by; a framed picture on the wall could be seen from any angle; glass-enclosed meters and instruments could be read without difficulty. Photographers would not be bothered by reflections on their lenses; makers of optical instruments would have greater light-transmitting power in their products; wearers of spectacles would no longer be aware of reflections from in back of them. These are among the possibilities indicated by laboratory developments which have been conducted with samples of glass treated with some of the nonreflecting films.

However, films so produced are soft and can be wiped from the glass with a cloth, it has been announced, indicating that the present films are not ones to be applied to store windows, framed pictures, etc., but the films do provide an extraordinarily useful tool for studying the application of the phenomena of interference to problems of light reflection. Glass so treated is not commercially available.

It was back in 1892, according to Dr. Blodgett, that H. B. Taylor, an English lens maker, found that a tarnished photographic lens had greater light-transmitting ability than did a clean lens. Now, as one result of the pure-science investigations of oil films and monomolecular layers—investigations which have figured prominently in G-E laboratory activities for several years—comes the announcement that the treating of glass surfaces to eliminate glare and increase light transmission is a reality.

The films are made in the laboratory in such a way that the light reflected from the outer surface is equal in intensity, and opposite in phase, to the light ray reflected from the surface of the glass itself. The two reflected rays neutralize each other, and there is no reflection.

It is possible to determine mathematically how thick the film should be for any specified wavelength of light. Ordinary "white" or daylight, however, is composed of light of various wavelengths, from blue of about 0.0000018 inch through all the colors of the rainbow to red of about 0.0000026 inch. The calculations, then, are made for one wavelength, as for sodium light, so that the resulting film totally extinguishes light of that wavelength and nearly extinguishes all visible light of other wavelengths.

Calculations show that the films can be of different thicknesses, of one-quarter the wavelength of the light or three-quarters or five-quarters. Dr. Blodgett actually found that the thinnest film satisfying the mathematical equation of one-quarter the wavelength of the light was most effective in diminishing reflection of white light.

It was in 1934 that a method was developed, in the G-E laboratory, for building standard films of known thickness. The method devised employs sheets of barium stearate, which have a uniform thickness of 0.0000001 inch. Each sheet consists of a single layer of molecules of barium stearate, prepared by placing a small amount of stearic acid on water containing a barium salt. The individual molecules of which stearic acid is composed endeavor to attach themselves to the water surface, with the result that the stearic acid spreads out over the water until each molecule has a place on the surface. The molecular layers are transferred to the glass surface by a dipping process at a rate of about 20 layers per minute. As the plate of glass is submerged it becomes coated with a film one molecule thick; as it is withdrawn from the water, a second monolayer is deposited. Repeated dippings of the glass build up the film to any desired thickness.

Dr. Blodgett's work has shown that built-up films of the soaps of certain fatty acids can be so treated that they will have the index of refraction required to form a suitable coating on ordinary glass or on any glass of higher refractive index.

Using a composition that consists of from 50 to 80 per cent barium stearate and the remainder stearic acid, a film of desired thickness is built. Then the stearic acid is dissolved away, leaving a skeleton of barium stearate on the glass. Air fills the spaces previously occupied by the stearic acid, so the refractive index of the skeletonized film varies according to the amount of stearic acid removed without shrinking the film. In order that a film shall reflect no light when built on glass, the composition of the film must be chosen so that the refractive index of the film is suited to that of the glass.

Even better in optical quality than those of barium stearate, Dr. Blodgett found, are skeleton films of cadmium arachidate, built up on glass in a similar way but with other chemicals. A film having 42 or 44 layers of skeletonized cadmium arachidate has a thickness of a quarter wavelength of sodium light.

If a piece of ordinary glass is placed near a bright sodium-vapor lamp, with a black background such as velvet behind the glass, the glass reflects a bright glare of yellow light. A glass coated with a nonreflecting film, on the other hand, appears as black as the velvet itself. Again, if a piece of glass, half of which is as clean as possible and the other half film-treated, is held against a sky background or in front of a sheet of white paper, the coated part will seem to be clean, and the clean part will seem slightly smoked.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

THE *ASAMA* COMES BACK.—Motorship and Diesel Boating, New York, N. Y., February, 1939. (Extract from an article by Tom White.)

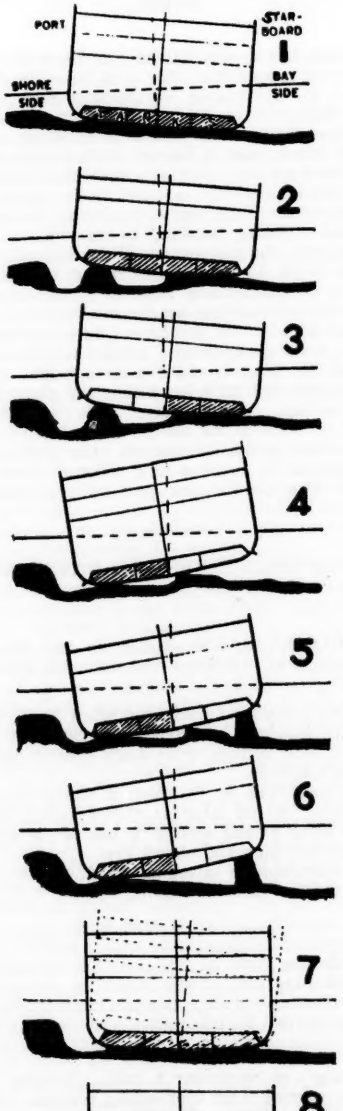
Occasionally, there's a marine miracle, but when N. Y. K.'s *Asama Maru* rolled in through the Golden Gate September 29th last her reappearance marked one of the closest brushes with death ever to befall a ship. Her salvaging was indeed a miracle.

Having staged a come-back in the face of almost impossible odds, she moved up to quarantine, just off Alcatraz, thence to her San Francisco pier, twelve months after being pushed around by one of the worst hurricanes in sea-going history, and left high and almost dry.

Some idea of the magnitude of salvaging the $7,000,000, 17,000-ton, Diesel luxury liner is gained from the following highlights:

Cost of salvage	$1,000,000
Weight removed	3,500 tons
Time required for refloating	138 days
Rock removed for refloating	7,800 tons
Dynamite used for refloating	2½ tons
Maximum number of divers	30
Salvage vessels	3

Ominous was the night of September 1, 1937. Shipping in the harbor of Hong Kong had been warned of an approaching typhoon. Wise in the ways of these scourges of the sea, Captain Kaneko of the *Asama Maru* moved his command to nearby Junk Bay, where she "holed in" for the blow.


PORT
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And what a blow! Even the Beaufort scale had no name for it, as the furies at their height whistled and shrieked at a measured velocity of 167 M.P.H., and the barograph sank to the 713-milimeter mark. Bang went the starboard cable, even though it was eased by the ship's engines; the port anchor dragged, and at 4 A.M. *Asama* was driven ashore.

Helping the elements to make a really complete job of it, was the chain of three circumstances which combined to send the big ship higher than she would have ordinarily gone: (1) an abnormally high tide, (2) being fresh from drydock, her draught was unusually light, and (3) having a light draught, she naturally presented more resistance area to the wind because of greater freeboard.

A careful survey revealed first, that the damage to *Asama's* bottom plates was not as extensive as had been feared, and that she was resting, only 90 feet offshore, partly on solid rock, partly on gravel and clay, and with a list of six degrees to starboard. Plans were accordingly laid to refloat her in December, but such was the magnitude of the job of blasting away the rock, that this date was set ahead to catch the high tide expected about March 15.

When she went ashore, *Asama* was drawing 23 feet 6 inches. The spring tides were expected to bring the depth to 15 feet 10 inches, the difference of 7 feet 8 inches having to be overcome by lightening her by some 6500 tons. But she carried no cargo whatever; consequently 2240 tons of fresh water and fuel oil were removed, also 1000 tons of machinery (two of her four main engines being taken out piecemeal through the ship's side), and all movable gear-davits, anchors, cables; and along both sides ten buoyancy tanks were fitted, these considered as canceling out a weight of 500 tons. This left 2500 tons to be accounted for, which was done by excavating four feet under her bottom.

Actual refloating was accomplished (see adjoining sketch) as follows: (1) when she went ashore, she rested as shown; (2) rocks were dug and blasted away from port side, some material being left to keep her in same relative position; (3) to prevent port-listing, sand bags were piled near remaining rocks; starboard deep tanks were pumped full; (4) when port side excavation was finished, sand bags were removed and port deep tanks filled with water while starboard tanks were emptied, giving her a seven-degree list to port; (5) excavation was started under starboard bottom; when finished, both shoring of water cement and sand bags were used; (6) showing rock removal, late February; (7) shoring and sand bags removed from starboard side, allowing ship to rest in normal position; deep tanks pumped full to keep her secure; and (8) with everything ready, deep tanks were emptied, and aided by buoyancy tanks, the vessel was refloated, March 11. The big liner underwent temporary repairs at Hong Kong, then proceeded under her own power—two remaining engines—to Nagasaki for complete overhaul, reinstallation of two disassembled main engines and replacement of ten damaged bottom plates.

Asama Maru was launched at the Mitsubishi Dockyard, Nagasaki, October 30, 1928. Her main engines consist of four eight-cylinder, single-acting Sulzer Diesels, developing a total of 16,000 H.P. and a speed of 21 knots. She measures 548 feet $\times$ 72 feet $\times$ 42 feet 6 inches, and accommodates 839 passengers, 239 first class.

A feature of the wreck and salvage of the vessel was the fine performance of the Sulzer Diesels shown in the engine room view below. These engines have been driving the big ship back and forth across the Pacific for ten years and are good for many more years of service. As noted above, it was necessary to take two of the engines out in pieces, to lighten the ship, but the two remaining engines were started when the ship was refloated and carried her without trouble to Nagasaki.

TANTALUM—UNIQUE METAL.—Industrial Bulletin of Arthur D. Little, Inc., Cambridge, Mass., January, 1939.

A recent announcement by the Fansteel Metallurgical Corporation of a hydrochloric acid gas absorption equipment in which all the parts that come in contact with the acid are of pure tantalum directs attention to this extraordinary metal and stimulates the imagination to wonder whether there may not be other uses for which tantalum is uniquely to be preferred.

An especially notable feature of the hydrochloric acid apparatus is its small size; it occupies only about one-tenth as much space as the common vitreous or ceramic equipment which it is designed to replace. Since tantalum is totally inert to the ordinary acids, except hydrofluoric and fuming sulfuric acids and at elevated temperatures sulfuric and phosphoric acids, it introduces no impurities into the hydrochloric acid. The metal may be used safely in contact with the usual acid liquids; it is attacked rapidly by alkaline solutions only if they are hot and concentrated. It is attacked by hydrogen gas in the nascent state, and has a strong affinity for oxygen at high temperatures.

Tantalum has an extremely high melting point of about 285 degrees C. It has a density of 16.6, about twice that of steel, and sinks in mercury. Its strength, however, is such that it may be used in thin sheets or tubes. Tantalum tubing with a wall thickness of less than 0.020 inch is reported to be safe for the confinement of steam under a pressure of 150 pounds per square inch, and the great density of the metal is not a serious disadvantage. Unannealed tantalum is about as strong as cold-rolled steel, and annealed tantalum is about as strong as annealed steel. It may be cold-worked about as easily as nickel, and becomes harder under the treatment at a slower rate than most metals do. It requires a vacuum for annealing. Ordinary machine tools will cut tantalum if carbon tetrachloride is used as a cutting compound. It may be made into fine wire which has about the same breaking strength as steel wire. For hardened tantalum wire the yield point and the breaking point are practically identical. Tantalum is used for spinnerets in the rayon industry, where it is said to retain its shape under the pressures which are used, and to resist erosion. It is cheaper than the precious metals from which the spinnerets are often made. Tantalum occurs in the minerals tantalite and columbite, both of them mixed tantalates and columbates of iron and manganese. If the tantalum predominates, the mineral is called tantalite; if the columbium, or niobium, as the Europeans prefer to call it, then the mineral is called columbite. Until 1937 the only producing tantalum mine in the world was one in the desolate Pilbarra District of Western Australia in a desert where water doesn't exist and where mining operations can be carried on only during or immediately after the rainy season. In 1937 a second mine was opened near the town of Tinton in the Black Hills of South Dakota.

Tantalum is not a metal which can be smelted from the ore. The concentrates require to be treated by an exactly controlled chemical process for the production of pure tantalum compounds. The chemically pure salts are reduced to powdered metal, which is pressed into bars by hydraulic pressure and sintered in vacuum furnaces at temperatures in the neighborhood of the melting point. The crystalline structure of the metal is controlled by hammering, by swaging, and by further heating in vacuo. Subsequent operations, such as rolling into sheets or drawing into wire, are carried out in the cold with vacuum annealing at intervals.

The effect of change of temperature upon tantalum is markedly different from its effect upon other metals, and necessitates special care in the design of apparatus in which it and several different metals are used. The linear coefficient of thermal expansion of tantalum is about half that of common

steel, four-tenths that of copper, and three-tenths that of silver. Its thermal conductivity is about that of steel, but it has the remarkable property of being easily wetted by aqueous liquids, of giving good heat transfer, and is reported to be a better material for the construction of heating coils than other metals in common use.

If tantalum is made the anode in an electrolytic cell, it immediately becomes coated with a thin, tenacious film of oxide—and the film, because of its high electrical resistance, shuts off the further flow of current. Such films are stable against potentials which do not exceed 200 volts or thereabouts. And tantalum electrodes are used in the "Balkite" rectifiers, where they constitute what amounts to a one-way valve for the electric current and produce from the lighting circuit a direct current which may be used for charging a storage battery. Batteries, charged in this fashion, are in fact used for keeping tantalum heating coils, etc., in the anodic state when they are used in metal or metal-lined tanks. The consumption of current is small because of the resistance of the oxide film. Care must be exercised always to prevent tantalum from becoming cathodic or exposed to nascent hydrogen. When it is at its best, its properties commend it for a variety of important purposes.

A REAL-HEIGHT METER.—The Aeroplane, London, England, December 14, 1938.

From the United States come stories of new aids to navigation, one of which in particular seems to come very close to our ideas of what the Radiaura should be. At present it is being used as an altimeter which will measure accurately the height of an aeroplane above the ground at any instant instead of merely giving the height in terms of pressure above sea-level, as does the ordinary barometric altimeter. But its inventors or sponsors seem to think that a modified version can be used to signal the presence of obstacles in front of the aeroplane.

Flying blind will never be safe until some kind of instrument to give the true height of the aeroplane above the ground is in general use. What is wanted, in fact, is an aeronautical version of the sounding lead used by ships. And curiously enough that is the basic idea behind the new American development. Only, instead of dropping a line with a lump of lead on the end of it, the aeroplane projects a continuous series of radio waves down to the ground which are reflected back with the speed of light,—186,000 miles a second, or thereabouts.

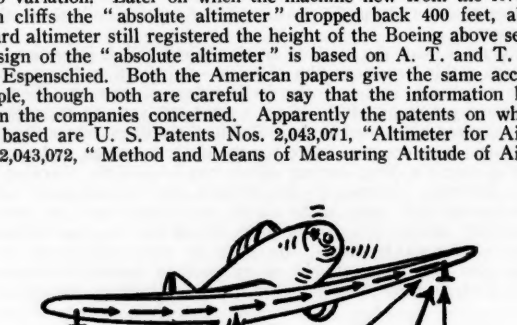
Ships at sea have been using an echo-sounding device for years with great success. The extension of the idea was tried out in the airship, the first *Graf Zeppelin*, but whereas sound waves behave satisfactorily in water, in air they are affected by weather and the nature of the terrain beneath the aircraft to such an extent as to be quite unreliable.

Hence the need to use radio. And one has to use ultra-short waves (Very High Frequency or V.H.F.) because such waves can the more easily be focused in something like a beam. They are also reflected in a satisfactory manner by the ground and by even man-made obstacles such as bridges and buildings,—and presumably other aeroplanes.

The instrument, called the Terrain Clearance Indicator, has been developed by the United Air Lines, Bell Telephone Laboratories and the Western Electric Co. in conjunction. It certainly seems to work, because in a demonstration over the Hudson River to our American contemporaries, "Aviation" and "Aero Digest," the "absolute altimeter" even recorded the passage over the George Washington Bridge by kicking back 250 feet momentarily

as the Boeing Transport in which it was being shown off flew over. Naturally, the standard aneroid, or barometer type, altimeter installed side-by-side showed no variation. Later on when the machine flew from the river over some high cliffs the "absolute altimeter" dropped back 400 feet, although the standard altimeter still registered the height of the Boeing above sea-level.

The design of the "absolute altimeter" is based on A. T. and T. patents by Lloyd Espenschied. Both the American papers give the same account of its principle, though both are careful to say that the information has not come from the companies concerned. Apparently the patents on which the design is based are U. S. Patents Nos. 2,043,071, "Altimeter for Aircraft," 6:23:36; 2,043,072, "Method and Means of Measuring Altitude of Aircraft," 6:23:36.



RADIO SOUNDING.—A DIAGRAM, FROM "AVIATION" (NEW YORK), TO SHOW THE PRINCIPLE ON WHICH THE NEW "ABSOLUTE ALTIMETER" WORKS. THE FREQUENCY OF THE TRANSMITTER IS CONTINUOUSLY CHANGING. CONSEQUENTLY THE REFLECTED WAVE FROM THE GROUND "BEATS" WITH THAT RECEIVED STRAIGHT ACROSS THE UNDERSIDE OF THE WING, THE FREQUENCY OF WHICH SIGNAL HAS CHANGED WHILE THE OTHER SIGNAL IS TRAVELLING TO THE GROUND AND BACK.

According to these accounts, the apparatus is made up essentially from a small transmitter with a power output of 5 watts mounted under one wing, and a small receiver mounted under the other wing. The transmitter is

distinguished by the fact that it works on a wave length of only 60 centimeters. The power is enough to give heights up to about 5000 feet and the instrument will work accurately down to within about 20 feet of the ground.

The transmitter works with a small di-pole aerial in the shape of a T about 6 inches across the head and about 6 inches high, which hangs upside down below the surface of the wing. The signal sent out keeps in a narrow beam which spreads in a cone immediately below with an angle of about 40 degrees.

The reflected signals are picked up again by a second aerial of the same type mounted under the opposite wing. This receiver also picks up the signals directly across the wing.

Now, the range of frequency sent out is varied 80 times per second continuously from the maximum to the minimum by a motor-driven variable-condenser. Thus the frequency of the transmitted signals varies with time. If plotted on a basis of time the curve of frequency would be in the form of the teeth of a saw. The received signals are in the same pattern, but are stepped along the graph because of the time which elapses between their transmission and receipt. This difference of time is almost infinitesimally small but it can be measured. The received wave is made to "beat" with the transmitted wave,—in the way that the unsynchronized motors of a twin-motored bomber "beat" or throb. The resultant current moves the pointer of a milliameter calibrated in feet.

The inventors have a program of work for another year before they believe that the altimeter will be perfected. The objects are to reduce the weight below the present 50 pounds and to improve the indications above 4000 feet.

Further experiments are being made with reflectors to narrow down the transmitted beam still more. Another line of research is to convert the instrument so that it can be used pointing directly forward to give a warning of any object ahead.

The inventors have in mind the future adaptation of the instrument into a kind of Radiaura to give warning of any other aeroplanes around and about. In this form the instrument would record the position, distance, and relative direction of movement of any other machine and its rate of approach or departure.

When the first series of tests are over, the Western Electric Co. plan to make enough indicators to equip all the fleet of United Air Lines. After this favored collaborating market has been supplied, the apparatus will be available for all who want it.

APPLICATION OF SUPERSONIC WAVES.—The Metallurgist (supplement to The Engineer), London, England, December 30, 1938.

Supersonic waves have recently been made use of to examine their physical, chemical, and metallurgical applications,[1] which are numerous. They have been used for destroying labile equilibria, starting chemical reactions and for studying their electro-chemical and photo-chemical effects. Supersonic waves have also been studied in relation to their effects on very small particles such as effects of a colloidal-chemical nature, the production of disperse systems, the aggregation and flake formation of smoke, dust, and fog particles. As far as the materials of construction are concerned, the waves have been applied to improve metallic constructional materials and also to the testing of materials. Much of this can no doubt be regarded as new as far as metallurgical applications are concerned.

Supersonic waves are waves with frequencies lying above those in the range of audible sound. These high-frequency waves can be transmitted in any

required direction, and, further, great energy intensities can be obtained. The dispersion of the waves depends on the conditions within the medium through which they are being transmitted.

The most important method of producing supersonic waves is that of converting electrical vibrations into mechanical vibrations. In this method, frequencies up to about 50 kHz are produced by a magneto-striction sound producer. What actually happens is that the waves are produced by the mechanical distortion of a ferro-magnetic body situated in a magnetic field—the so-called magneto-striction—but for higher frequencies a piezo-electrical sound producer is used exclusively. In this way, frequencies up to 200 million Hz can be reached. By piezo-electrical phenomena is meant the well-known mechanical distortion of certain crystals when placed in an electric field which may be traced to movement of the ions. This distortion only occurs if the electric field has a component in the direction of what are known as electrical axes of the crystals. Mechanical vibrations are set up in the crystal of the same frequency as the applied alternating field. Mechanical devices employing supersonic waves were in use in the Great War for locating the presence of submarines.

In order to understand all the effects resulting from supersonic waves, it is necessary to have a knowledge of the physical properties and effects of intense waves. The influence of these waves always implies mechanical loading, and therefore phenomena are to be expected which arise from mechanical shocks. Where pressures are exceptionally low, supersonic waves may be used for degassing liquids, and there are other numerous possibilities of a physical nature. The effect of bombardment with intense supersonic waves can be seen, in its destructive aspect, by the roughening produced on the edge of a steel knife—after a bombardment lasting ten minutes. The actual damage is in this case produced by "cavitation" effects resulting from the waves.

So far only the mechanical effects of supersonic waves have been referred to, yet their thermal effects require consideration. The periodic thermal effects produced by adiabatic temperature changes are so very small even in the case of the strongest supersonic wave producers that negligible results may be expected. On the other hand, the nonperiodic temperature changes resulting from the absorption of supersonic energy can reach considerable magnitudes and must be taken into consideration when they are not compensated for by cooling. Specially strong heating occurs at boundary surfaces, and pieces of cork may be burnt when coming into contact with a supersonic wave emitter. Also, consequences of an electrical nature may be expected with the largest sound strengths.

The vibrations set up in bodies by supersonic waves have already been referred to, and phenomena resembling mechanical "shaking" would therefore be expected to destroy labile conditions of equilibrium. The consequences of the like require, therefore, no further explanation, and the following instances may be cited:—The avoidance of superheating at boiling or melting points, the crystallization of supersaturated solutions, and the explosion of substances particularly susceptible to the touch.

Chemical reactions which arise as a result of wave treatment may be divided into two groups from the point of view of the probable mechanism concerned. First, reactions which occur as a result of activation of dissolved gases following cavitation effects, and secondly, the breaking down of highly polymerized substances. Various oxidations, as well as the formation of very small quantities of acids containing nitrogen, and of ammonia, are the best known of the first group. It could be shown that these reactions would not occur in the absence of dissolved gases in the liquids. They are dependent on the formation and breakdown of cavities. The amount of the substances produced, resulting from exposure to the waves, is very small. Such sub-

stances as gelatin, gum-arabic, and cane sugar, etc., can be separated into molecules of simpler structure. Again, it has been found in some cases that speeds of chemical reaction can be increased by the action of supersonic waves. In some cases the increase results for the activation of dissolved gases; in others thermal effects may be chiefly responsible.

The first systematic experiments on the electro-chemical effects of supersonic waves were made by Schmid and Ehret,[2] who observed that the waves affected the passivity of metal. They found that supersonic waves affected the passivity as a result of mechanically breaking up the protective covering layer, for example, in the case of iron in concentrated sulphuric acid, as well as affecting the chemical passivity, for example, in the case of iron in concentrated nitric acid. The passivity of the iron could in both cases be hindered or decreased as a result of such wave treatment. The effect of the waves consists obviously in the breaking loose of the mechanically superimposed covering layer promoting passivity. The changes involved in the action on the chemical passivity are not explained.

There are possibilities in the laboratory of precipitating aluminium and magnesium electrolytically out of aqueous solution by means of supersonic waves, and again of nickel-plating. In most cases depolarization occurred on exposure to these waves, in exceptional circumstances polarization. The method has shown quite remarkable results regarding the electrolytic separation-potential of hydrogen. Young and Kersten report that when iron is deposited electrolytically on a copper cathode a deposit in the form of fine parallel ridges is produced by the action of supersonic waves, the distance between the ridges corresponding to half their wave length. A similar form of ridge formation is produced on developing a photographic plate, after exposure to the waves, which illustrates the chemical action induced. Luminescence in liquids is also produced.

Attempts to disperse metals by means of supersonic waves often lead only to very coarsely dispersed systems. According to Claus, highly dispersed systems are obtained when metals during electrolysis or chemical reaction are exposed to supersonic waves. On the contrary, other investigations have shown that nonmetallic particles such as smoke, dust, and fog, may tend to collect together or form flakes. This occurs to a very considerable extent judging by the rate at which the particles settle under gravity and by their appearance.

Claims have been made that the physical properties of steel, especially the strength, have been improved by high-frequency vibration, as well as a considerable reduction in the time required for nitriding and in depth of penetration of the nitrogen. There are, indeed numerous metallurgical processes which proceed at considerably greater speeds, or proceed at the same or even at higher speed with lower temperature, as a result, it is stated.

Sokoloff[3] has shown that molten zinc, when allowed to solidify under the action of supersonic waves of high frequency (650 to 4500 kHz) showed a different crystal structure compared with other melts when solidified without the wave treatment. The crystal structure, as a result of the wave treatment, was of finer grain, and, it should be remarked, of more needle-like structure. It has further been suggested that melts could be degassed by the use of these waves. It is unnecessary to make a too sharp distinction between ordinary sound waves and supersonic waves as far as their effects are concerned, since many effects found with supersonic waves could afterwards be produced by the use of sufficiently intense sound waves.

The apparatus used by Schmid and Ehret in their experiments on the effect of supersonic waves on molten metals during solidification has been fully described by them. Their apparatus has only been developed as far as necessary for small-scale laboratory experiments.

The accompanying illustration due to Schmid and Ehret shows the effect of audible sound waves on pure metal and alloys. A marked increase in grain refinement has taken place.

These results suggest that the formation of coarse dendritic structures is resisted by sound waves; for example, in the case of silumin one can observe clearly a breaking up of the needle-like structure. The increase in the fineness of grain corresponds also to an alteration of the mechanical properties. For example, the Brinell hardness is 52 ± 1 kilos. per square millimeter for antimony exposed to the sound waves, and is 34 ± 1 kilos. per square millimeter for antimony unexposed, while the corresponding values for duralumin are 96 ± 4 kilos. per square millimeter, and when unexposed 78 ± 7 kilos. per square millimeter. In the case of silumin an alteration in Brinell hardness could not be determined with certainty.

Masing and Ritzau[4] have experimented with sound waves of yet lower frequency (500 Hz). In particular, they attempted to produce a fine dispersion of lead in aluminium to make this material more easily machinable in automatic machines. Schmid and Ehret carried out similar experiments and by using a stronger wave emitter were able to produce a considerably better result. Lead added to molten duralumin as lead chloride which was reduced by the aluminium resulted in large lead inclusions. The effect of treating this material with sound waves of 500 Hz and 10 kHz was to disperse the lead so as to form much smaller and numerous lead inclusions. This left no doubt whatever that a grain refining action takes place and that the distribution of one metal in another can be altered.

No further results of the effect of supersonic waves are, it is stated, available regarding other metallurgical processes, but it is perfectly clear that the possibilities of sound-wave treatment have not been exhausted, and even the simplest mechanical devices for producing ordinary vibrations may perhaps yield important practical results.

Another application of the waves is in testing materials. Tubes or rod of ferro-magnetic material may be torn asunder by subjecting them to the magneto-striction effect with large amplitudes of vibration. Newton Gaines[5] has pointed out that determination of the tensile strength of material for alternating load can be carried out in very short time by means of high-frequency vibrations. With sound frequencies of 10 kHz, it is possible already to reach thirty-six million load reversals in one hour. Further investigation is necessary to find if the high-frequency alternating strength is similar to the alternating strength under low-frequency load reversals, or whether at least a simple relationship exists between the two strengths. According to preliminary determinations of Gaines, the strength values obtained by both methods appear to agree in order of magnitude with one another.

Iron and steel specimens allow supersonic waves to pass through them very easily. It is possible to pass the waves without difficulty through a depth of many meters of steel provided the metal is free from defects. However, if discontinuities occur in the steel, such as cracks or blow-holes, then the passage through of the waves is greatly restricted and only a small proportion is transmitted while back reflection of the waves and also absorption under certain circumstances is very great. Since these waves spread out or disperse in a material like rays issuing from a source, it is possible to discover the presence of defective places in a material by supersonic wave "shadows," if the direction of the waves travelling backwards is known. This method of locating failures in a material is at present in an early stage of development, and requires further study in view of its practical possibilities.

The operation of agitating moulds for the purpose of producing grain refinement during solidification of molten metal has been the subject of investigation already and is well known.

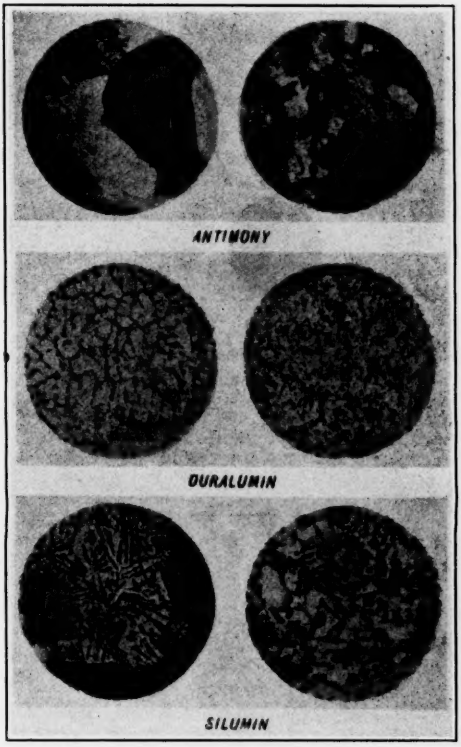


PHOTO-MICROGRAPHS OF MELTS SOLIDIFIED UNDER THE ACTION OF SOUND WAVES (RIGHT SIDE OF ILLUSTRATION) AND IDENTICALLY SIMILAR METALS NOT SUBJECTED TO SOUND WAVES (LEFT SIDE).

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SOME ASPECTS AND PROBLEMS OF THE DEVELOPMENT OF HIGH-SPEED CRAFT AND ITS MACHINERY.—Shipbuilding and Shipping Record, London, England, February 9, 1939. (An abstract of the Eleventh Thomas Lowe Gray Lecture delivered by H. Scott-Paine before the Institution of Mechanical Engineers, London, January 6, 1939.)

The round bilge hull shell depends to a large extent for its stability upon the sheer weight of machinery, boilers, etc., and in the absence of this load the shell would of itself be unstable. This has, in my opinion, been a great deterrent to the hull designer and the engineers in reducing the weight of either steam or Diesel machinery, which I feel is unnecessarily heavy. The hard-chine boat, on the contrary, is extremely stable as a shell and there is therefore every inducement to lighten continually, not only the structure of the hull itself, but everything from the machinery to the smallest fitting.

There is a further point of comparison. A destroyer or similar vessel loses stability as her speed increases, whereas the hard-chine boat, if properly designed, increases in stability with increase of speed.

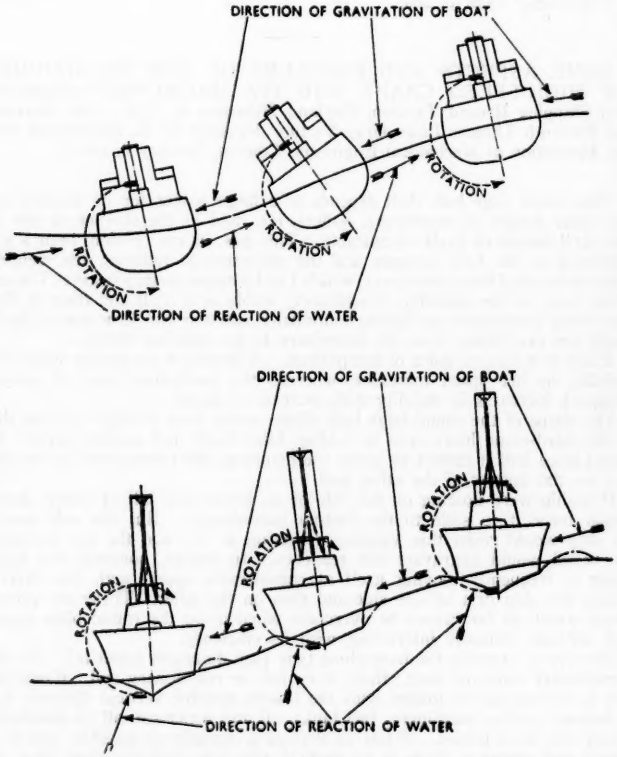
The shape of the round bilge hull allows much freer rolling than the shape of the hard-chine hull; even by adding bilge keels and similar devices to a round bilge hull it cannot be given the damping effect possessed by the chine and the flat bottom of the other hull.

If a ship were floating on the side of an immovable hill of water, gravity would force it to slide to the bottom immediately. But the side area of the ship would resist this, causing a canting action, and the top hamper of the vessel would aggravate this tendency. In reality, however, the hill of water is frequently moving itself at considerable speed, with the effect of rolling the ship first on one side and then on the other. These are primary forces which so far cannot be overcome when using the round bilge type of hull, without seriously interfering with its efficiency.

Now let us examine the hard-chine type (see diagrams opposite). Its shell is extremely stable of itself; there is no roll or reactionary roll. Everything that it carries can be loaded with the lowest possible vertical distance from its bottom, so that machinery, fuel tanks, oil and water can all be installed at a very low level indeed. It has as shallow a draught as possible, and to all intents and purposes there is no vertical side area and therefore little side resistance to the tendency to slide down the hill of water and hence no inclination to roll; on the contrary, when it tends to slide, the action of the "V" bottom brings it upright, in contradiction to the action of other types of ship.

Now let us examine the question of sea-keeping. When driving into a head sea, or with a following sea, there is, in the case of the round bilge boat at normal or slow speeds, a body of water lifting the stern above the fore end while the head wave when reached by the bow has to pass along a considerable length of the ship to supply sufficient buoyancy to lift it. At faster speeds the hull is in a diving position much longer, owing to the difficulty of the head wave in finding sufficient area to lift the weight of the ship, augmented

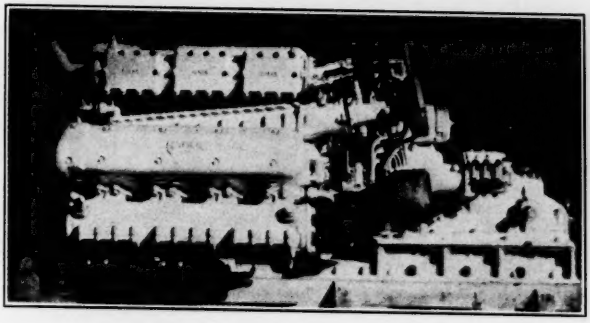
by increased speed and by the possible scooping of water aboard. Speeds must therefore be frequently reduced in rough weather, and when driving faster great caution must be exercised on account of the occasionally much larger sea which always prevails, and which has been the cause of some bad accidents.



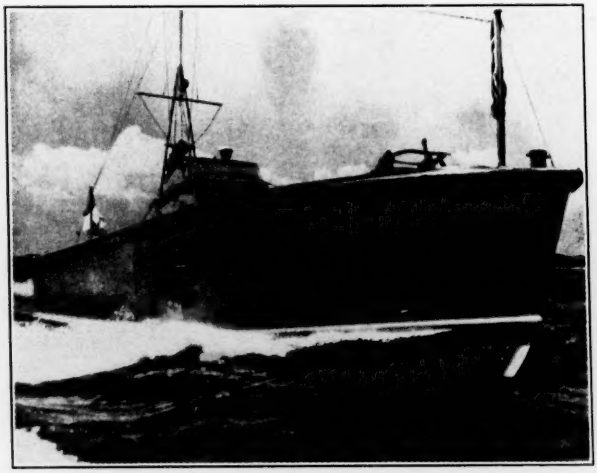
DIAGRAMS OF REACTIONS BETWEEN HULL AND SEA.

What happens to the hard-chine motor torpedo boats, which we have been responsible for bringing into being? In a 45-M.P.H. wind and an 8-foot sea of reasonable pitch, these boats can be unhesitatingly driven up to the limit of their speed, which is 40 knots, a performance which no other boat can equal, so far as I know. It should be remarked that if this size of the sea were scaled with the size of the motor torpedo boat it would produce the most severe gale conditions for, shall we say, a ship of 2000 tons.

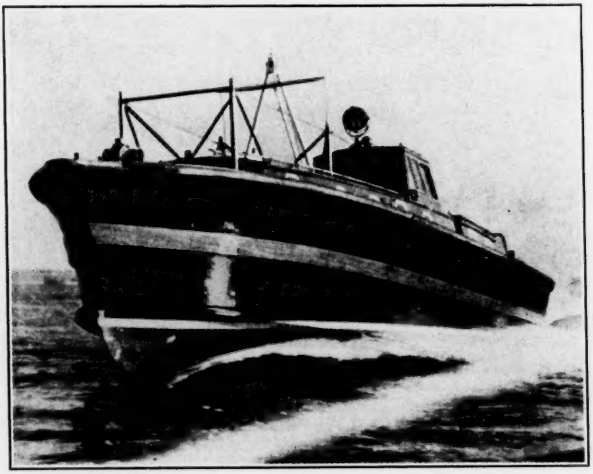
The design of the fore part of the hull makes it quite impossible to dive into the sea, as in the case of the other hull, and one is able after a few



THE P.M. "SEA LION" MARINE ENGINE.



FLOTILLA LEADER OF THE FIRST MOTOR TORPEDO BOAT FLOTILLA.



40-FOOT HIGH-SPEED PATROL LAUNCH FOR AIRCRAFT RESCUE WORK IN TIMOR SEA.

minutes' practice to control the speed of contact by use of the throttles. At the moment when experiencing resistance to the forward speed the throttles should be closed; the boat will then take its bearing by the bow and the throttles may be opened again. Sight as well as feeling helps to master the technique of this. Although the boat does not dive, it can be driven fast enough into a steep short-pitched head sea to plough the sea and momentarily retard its forward speed considerably, but here again by the technique of closing and opening throttles, which I have described, continuous high speeds can be maintained.

As I have mentioned before, lightness of construction and of machinery is of the greatest possible importance. The 1935-37 motor torpedo boat, without fuel, oil, or armament, but otherwise complete, weighs approximately 12 tons; when fully laden its weight is increased to 21-22 tons, but its speed is only decreased from 40 knots to a fraction under 38 knots.

This light construction also permits remarkably high acceleration and deceleration—from 8 knots to 40 knots in 7½ seconds, or from 40 knots to 8 knots in 3 seconds. These remarkable figures are the result of investigating every possible means of saving weight, and from brass screws and copper nails to special propeller metal we have demanded and found lightweight, high-tensile materials throughout the whole of the structure of the boats.

"Perspex" has replaced glass; longitudinal members of girder construction have replaced solid planks of timber; the scientifically constructed framework, pressed and laced together, has a strength-weight ratio unapproached before except in aeroplane construction; high-tensile material has enabled the size of the wood screws, of which tens of thousands are used in a single boat, to be reduced; the propeller shafts, brackets, and rudders are constructed of special material which has reduced their weight as compared with a few years ago by 70 per cent; tanks have been reduced in weight to 1 pound per gallon, and since my latest design of motor torpedo boat carries approximately 7 tons of petrol, this saving is of great importance.

All deck fittings are made of salt-water-resisting alloy of high tensile strength (24 tons per square inch). High-tensile steel bolts and nuts of small diameter are used throughout, as thousands of these are required in the construction of a boat. The ceaseless quest for reduction of weight has been pursued even to the extent of engaging laboratories in the search for lighter materials, of greater strength, for special purposes. Electrical fittings presented a difficult problem and were subsequently made by ourselves to our own specification. They are all watertight, sparktight, and fully screened for wireless telegraphy.

The weight of my latest motor torpedo boat, complete with her Rolls-Royce-Power-Merlin marine units, but unloaded, is exactly 10 pounds per horsepower.

When I first contemplated the building of the motor torpedo boat and had roughly designed it on paper, it was immediately apparent that nothing could be done until suitable machinery had been found. We purchased aircraft engines of the water-cooled type from Germany, France, and England, and eventually decided upon the 500-H.P. Napier *Lion* aero-engine. We obtained second-hand engines from the Air Ministry, converted six ourselves, and brought them to a state of very reasonable efficiency.

We then made arrangements with the Napier Company to build a suitable engine for us, which, while having the general characteristics of the aero-engine, was considerably modified in all directions; a new crankshaft had to be made; the old airscrew reduction gear and housing were removed, involving a new upper half to the crankcase; the cylinder block was completely redesigned with a new metal of thicker gauge for the water jackets; the

valve gear was redesigned; the pistons were modified to allow of indefinite slow running; and the old complicated aircraft carburetor system was completely replaced by the straightforward "Amal" type of carburetor of special construction.

On our part the ahead and astern gear, electrical starting gear, salt water pumps, petrol pumps, exhaust manifolds, etc., were built and assembled at our own works. The fresh-water and oil circuits of the engine are equipped with salt-water cooler. The fresh-water circuit is a closed circuit with a circulating pump; delivery is from the engine to a header tank of large capacity and then by gravity, aided by the action of the pump, through the cooler. The cooler gear is fitted with tubes as thin as possible and great care must be taken that no leakage takes place, for any salt water entering the fresh-water circuit causes rapid damage to the cylinder walls; the material of the water jackets, having a much higher resistance, hardly suffers at all. This is so important that to the daily routine of examining the oil and petrol filters must be added the testing of the fresh water for saline content.

With the modifications outlined above, this engine fulfilled all my requirements. In less than three years engines totalling over 150,000 H.P. have been built. These are in service in many parts of the world, run by engineers quite unfamiliar with this type of machinery, without any kind of serious trouble. The engines run for 700 to 800 hours without overhaul, and this period is being raised to 1000 hours. They have, I believe, the lowest petrol and oil consumption of any marine engine of their power. The total weight of the whole engine with its gear is under 3 pounds per horsepower, and it is built to withstand the hardest treatment.

In conclusion, I should like to mention my latest design of boat. The first motor torpedo boats were built as experimental and training flotillas. They were provided with 18-inch torpedoes and eight Lewis guns mounted in batches of four. These guns were mounted on Scarff ring mountings and sunk into the deck, where a man was relatively secure from the boat's motion, allowing him to pay full attention to the laying and training of his gun.

My idea and desire was not to build a boat to carry 21-inch torpedoes until we had at least 18 months to two years' experience under actual service conditions of the first type of boat. During this time I had been experimenting with what I conceived to be a superior type of hard-chine development, and we commenced construction of the new 21-inch boat in May of this year.

This boat carries two 21-inch torpedoes or four 18-inch torpedoes, and carries two 20-millimeter and one 25-millimeter guns in weatherproof gun turrets, oil or electrically operated. It has a speed approaching 50 knots when light, and over 43 knots when full war load. It incorporates many new ideas and modifications, and a most conspicuous part of the whole of the design of the boat is that it has a smaller target silhouette than the smaller 60-foot boat. It has no mast or deck fittings of any sort, and is extremely difficult to see.

Its machinery consists of three 1000-H.P. Rolls-Royce-Power-Merlin engines. The Rolls-Royce engineers at Derby worked in the closest co-operation with us; we gave them a difficult set of requirements, which they carried out in what I should consider to be the shortest time on record for such work.

We all hope that this design of hull and machinery may constitute an important step forward in the technical development of both British marine engineering and shipbuilding; what is perhaps of even greater consequence is that we are providing the Empire with marine defense units of extreme mobility. It is to be appreciated that these motor torpedo boats, with their shallow draught, enabling them to operate in very shallow water as well

as at sea, carry the same destructive power with their torpedoes as the present-day torpedo boat destroyer. Again, because of their shallow draught they can run over minefields without danger, and they cannot be torpedoed. They can elude bombing and defend themselves against machine gun attack from the air owing to their great mobility, and can outrun anything in any weather conditions, while under cover of night they can attack with deadly results.

LATEST DEVELOPMENTS OF THE BENSON BOILER.—Mechanical Engineering, the American Society of Mechanical Engineers, New York, N. Y., March, 1939. (By Francis Hodgekinson, Consulting Engineer, New York. Contributed by the Power Division and presented before the Metropolitan Section of the American Society of Mechanical Engineers, New York, N. Y., October 19, 1938.)

The author makes no pretense of being an authority on the design and operation of modern boilers. This paper treats the subject more from the standpoint of the designer of steam turbines. The subject matter is largely a communication from Germany on the latest developments and applications of the Benson boiler.

Before introducing the communicated matter, the author would like first to refer to earlier considerations on this important subject, review briefly the employment of higher pressures in this country, and point out reasons that led certain engineers of the Westinghouse Company to recommend to that company the desirability of its acquiring a license for the construction and sale of Benson boilers.

Many years ago engineers occupied in the design of steam turbines recognized the gains in efficiency that were to be obtained by employing higher steam pressures. In those days, however, the price of boilers increased so much that the improved efficiency could not be justified.

Installations made during the early twenties, employing pressures as high as 600 pounds per square inch at a temperature of 750 degrees F.—then believed to be a maximum safe temperature—employed reheating to reduce the moisture content in the steam in the lower ranges of steam expansion. Reheating was found objectionable because of large pipes to and from the engine and boiler room, and also because of the necessity of somewhat complex regulating apparatus on the low-pressure turbine element to prevent overspeeding on loss of load because of the steam enclosed within the reheater and connecting piping. These reasons led engineers in this country to strive for higher steam temperatures employing as high pressures as may be consistent with reasonable moisture content in the exhaust steam; until now temperatures as high as 950 degrees F. are being employed and 1000 degrees F. offered. Concurrently with this, means more or less successful were devised in connection with the low-pressure turbine elements for draining away at least some of the moisture as it is precipitated during steam expansion. From the turbine designer's standpoint, or at least in the author's opinion, it would seem that further increases of pressure combined with lower operating temperatures and reheating is a lesser evil. The reduced available work because of operation with a lower initial temperature can be more than made up with an appropriate application of reheating.

A boiler was built by the English Electric Co., of Rugby, England, to the account of Mark Benson in 1923. Following some trials and for some time thereafter, all further development was undertaken by Siemens-Schuckert Werke in Berlin.

During the succeeding years the author had several opportunities for discussion with Siemens-Schuckert Werke in Berlin and made studies of the influence of the Benson boiler on power-station economics; and it seemed, following the working up of turbine designs, that great gains could be obtained by its means and by operation at critical pressure or higher. It should be understood that during these times it was supposed that a "once through" boiler, comprising a tube system in which feedwater was admitted to one end and superheated steam discharged from the other, must, in order to operate with stability, operate at least with critical pressure. In practice, steam at the critical pressure was throttled to some lower pressure, 1500 to 2500 pounds per square inch, or some pressure suitable for the prime mover, and then superheated before use.

The studies made by the author led the Westinghouse Company to look further into the merits of the Benson boiler; a report of engineers who then spent some time in examination in Germany resulted in the company's acquiring an exclusive license in 1933. At this time it was learned that it had been shown that it was not imperative that this type of boiler be operated at the critical pressure, it could be operated at any pressure above, say, 500 pounds per square inch, which resulted in the development in Germany of a system of operation with pressure varying in response to load demand.

The Westinghouse engineers recognized that this type of boiler offered reduction of cost at least in the moderately higher ranges of pressure because of the absence of drums and that it could operate at higher pressures than could boilers that are dependent upon circulation, the result of convection currents, and upon the steam's separating from the water within drums and the like. It presented an element of safety, because in case of any rupture, the result of pressure or temperature could cause little injury beyond interruption of service. It offered no gain in boiler efficiency, for obviously, any type of boiler can be as efficient as another if combustion is correspondingly complete and flue-gas temperatures are correspondingly reduced by heat-absorbing boiler surfaces. The important point seemed to be what could be accomplished in power-station economics by a unit comprising this type of boiler operating with extremes of pressure and a turbine system with reheating and regenerative methods of heating feedwater.

The principle of operating with variable pressure presented a simplification of the turbine inasmuch as, except for an emergency governor to prevent overspeeding, there is no need of valve gear controlling steam flow at the inlet to the turbine, although means responsive to the speed of the turbine may be employed for controlling feedwater supply and elements of combustion. The somewhat complex and costly means of automatic nozzle control whereby nozzle groups come in and out of action according to load variations, thus rendering the maximum available work at fractional loads, become no longer necessary. This principle permits the turbine to sustain enormous overloads without the addition of any special valve gear or by-passing means. It was significant that when operating with variable pressure and with proper allowance for vacuum variation with load, the isentropic heat drop to condenser pressure remains approximately constant down to low fractions of output; also, the total steam volume remains constant so that except for the lowest-pressure turbine elements the turbine proportions are appropriate for any internal output, and the turbine steam path therefore has a nearly constant efficiency. These points are discussed later.

It seemed that the exploitation could be best accomplished by the most intimate collaboration between the boiler and turbine-apparatus designers, rather than by a boiler manufacturer alone. The Westinghouse Company made several tentative proposals; in certain cases detail designs and cost estimates were made for a complete superposed plant, which showed complete justifica-

tion for the investment. The Benson system appeared to be the next rational step in power-station economics.

That the company, for good reasons satisfactory to itself, decided, at least temporarily, to abandon development, is beside the point as to the value of the German development.

The German communication states that the Benson boiler has been developed by the Siemens-Schuckert Werke in Germany in recent years in a way that should prove interesting for American engineers.

The Benson boiler is a boiler with forced water circulation and was developed originally for operation at the critical temperature (706 degrees F.), which corresponds to a vapor pressure of 3200 pounds per square inch. In its simplest form, as shown in Figure 1, the Benson boiler consists of a heated tube through which water is forced and evaporated and superheated during this process. It had been the idea of Mark Benson, the inventor, to produce steam without any sudden increase of the volume and without ebullition and thereby to do away with the boiler drums which in normal boiler installations serve to separate steam and water. Experience with the first few installations showed that the Benson boiler is not limited to operation at the critical pressure, but can be operated at any desired pressure.

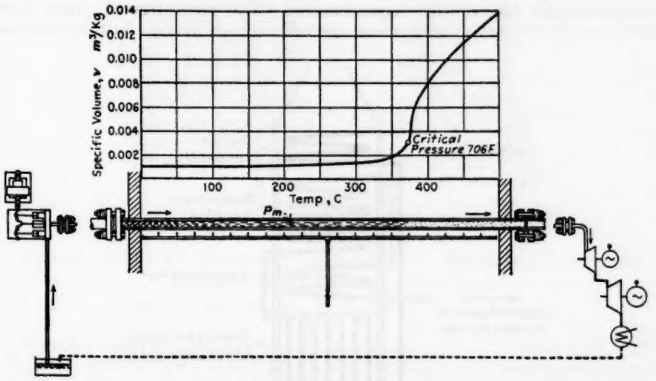


FIGURE 1.—SCHEMATIC DIAGRAM OF A SIMPLE BENSON BOILER FOR OPERATION AT THE CRITICAL POINT.
(The Curve Shows Volume Plotted Against Temperature.)

In the first large installations of the Siemens-Schuckert Cable Works in Berlin-Siemensstadt, the Langerbruegge Works of the Centrales Électriques des Flandres et du Brabant in Belgium, and the steamer *Uckermark*, the following unforeseen difficulties were encountered: As is well known, all feedwater contains varying amounts of salts which, in the case of normal drum-type boilers, accumulate in the water contents of the drums and are removed by continuous or periodical "blowdown" or rendered innocuous by the introduction of soda compounds. In the Benson boiler, these salts are deposited on the tube walls when the steam and water mixture changes to dry, saturated steam. In such a way a locally limited layer of salts is formed inside the tubes. This layer has the same heat-insulating effect as

scale. In the first installations in Berlin and Langerbruegge, the zone of salt deposits was in the radiant-heat-absorbing tubes, i.e., those tubes exposed to the most intense heat.

As a consequence, the tubes became overheated, and some of them burst after being in operation for a few days. The cause of the failure of tubes, which also had occurred in some smaller and earlier boilers, was at first obscure, because when a tube that had failed was removed, it was found free from any salt or scale deposit. The substitution of more heat-resisting material resulted in no remedy. The fact was that a deposition of salts reduced the heat-transfer rate sufficiently for the metal of the tube to become overheated and that the salts went back into solution when water was circulated during the process of taking the boiler out of service. After recognizing the real cause, that part of the heating surface, in which salts had been deposited, was relocated to zones of lower flue-gas temperatures, so that an appreciable layer of salts did not result in any dangerous increase in the temperature of the tube walls.

The improved arrangement of the heating surface resulting from the experiences mentioned in the foregoing is shown schematically in Figure 2. The boilers at Langerbruegge, in the S.S.W. Cable Works, and on the steamer *Uckermark* were reconstructed in this way. Figure 3 shows the Langerbruegge boiler after reconstruction. The reconstructed plants have now been in satisfactory continuous operation for six years. Salt deposits are

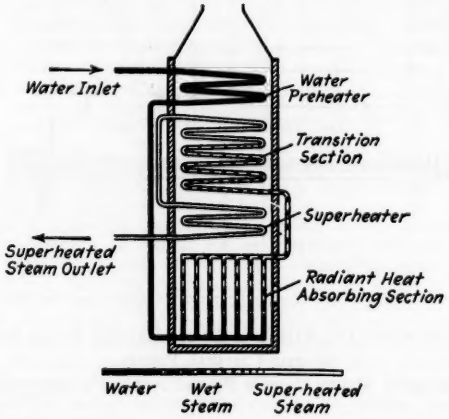


FIGURE 2.—ARRANGEMENT OF HEATING SURFACE OF THE BENSON BOILER WITH TRANSITION SECTION.

flushed out periodically. For this purpose, the boiler is shut down for a short period, and water is pumped through the tube system for about one hour with a flow corresponding to about one-third of the normal boiler rating. The frequency of this flushing depends on the condition of the feedwater. In plants using condensate for the feedwater, and where distillate is used also for make-up water, the flushing need not be carried out more frequently than once in three months.

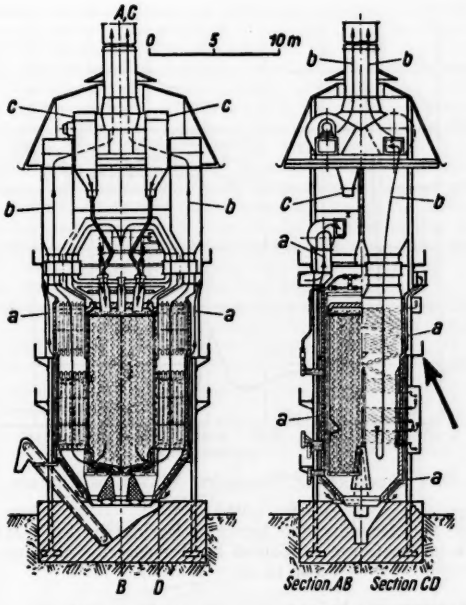


FIGURE 3.—BENSON BOILER AT LANGERBRUEGGE (BELGIUM), GENERATING 220,000 POUNDS OF STEAM PER HOUR.
(Zone of Salt Deposits Is Indicated by the Arrow.)

Figure 4 shows the results of such a flushing process in the S.S.W. Cable Works. Each process of shutting down and starting a Benson boiler automatically flushes the boiler by the nature of the process. Upon starting, water is pumped through the boiler by way of a special starting pipe, which ends in a settling reservoir or also in the reservoir of a cooling tower. The fire is ignited, the water first becomes heated, then changes to a steam-and-water mixture, and finally leaves the boiler in the form of superheated steam, whereupon the starting pipe is closed and the boiler is connected to the high-pressure steam system. This process is reversed when the boiler is to be shut down. Then the boiler is slowed down to the smallest possible load; the starting pipe is opened and at the same time the boiler is disconnected from the steam system; the fire is reduced until it is extinguished; and then water is circulated by means of the feed pump until clean water leaves the boiler. During this process, salts deposited in the boiler return into solution as already stated. Starting up the next time will then entirely remove any salts that remain. While it is possible to provide for an arrangement to permit flushing of sections of the boiler during operation, this has not yet been found necessary in Germany, since in 90 per cent of all cases it is always

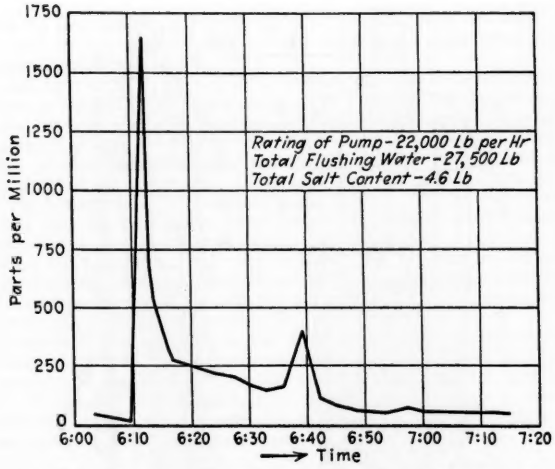


FIGURE 4.—SALT CONTENT OF FLUSHING WATER OF BENSON BOILER IN S.S.W. CABLE WORKS.

(Most of the Salt Deposits Are Removed During the First Minute. The Second Peak in the Curve Is Caused by Temporarily Shutting Down the Pump to Save Water.)

possible to shut down the boiler temporarily for flushing; furthermore, boilers are usually taken out of service for other operating reasons at more frequent intervals than once in every three months of continuous operation.

It has been recognized in Germany that only condensate should be fed to high-pressure boilers of any type or system, including normal drum-type boilers, since otherwise salt deposits in the machines connected to the boilers are unavoidable. In plants where large amounts of steam are used for heating and industrial purposes, and where the condensate is impure, or much of it is lost, the German practice employs heat exchangers in which steam from the high-pressure turbine system is condensed, the evaporated steam going to a heating system. This practice is also employed in the United States when condensate from a heating system is either not returned, or, if returned, is contaminated.

With the advent of steam pressures of 1200 pounds per square inch and higher, difficulties have been experienced with drum-type boilers because of salts being carried into the turbine and choking the blade passages, the salts being carried over by moisture particles. The separation of steam from water is more difficult the higher the pressure; it depends upon the relative density of steam to water and the amount of relieving surface of the water. This difficulty has been greatly ameliorated by the adoption of various means of washing the steam with fresh feedwater before it leaves the drum. Similar difficulties have been occasionally experienced with Benson boilers, but, it is stated, only when because of some inadvertence, raw water has leaked into the system.

The salts present in a Benson boiler during the last fraction of evaporation have a degree of adhesiveness while the crystals are being formed and

attach themselves to the tube walls. There are, however, certain kinds of salts that do not possess any adhesive properties, but it is stated that they generally deposit themselves with the adhesive salts and so may be readily flushed away. In the event of deposition of any insoluble salts, they may be removed by flushing with a weak solution of hydrochloric acid without injury to the heating surface. The original S.S.W. Cable Works boiler and the Langerbruegge boiler have each been once so treated during their lifetime of some six years. It is stated that the turbines of the Langerbruegge installation have never experienced any choking of turbine passages.

It would seem to be a point that in the Benson boiler the evaporation is of freshly admitted feed-water and that a large portion of the liberated steam does not bubble through water in a drum in which the water may have a high salt concentration. Dr. Michel, of the Hamburg-American Line, who has had ships equipped with Benson boilers under his charge, states that " the Benson boiler carries over less salts to the turbine than are fed into it, since there are deposits in the tubes and, even at the highest ratings, there is no priming and foaming." The amount of salt carried over as a function of the salt concentration in the feedwater is shown in Figure 5 (curve *b*). It should be

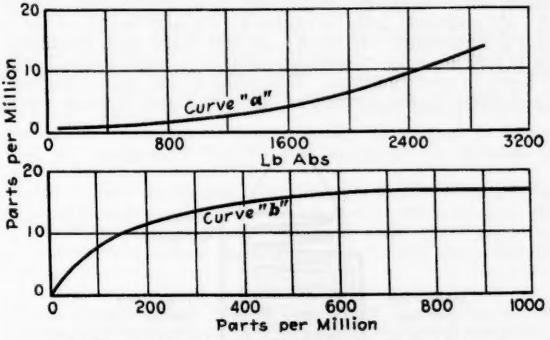


FIGURE 5.—SALT CONTENTS OF SUPERHEATED STEAM.

(Curve *a*, as a Function of the Operating Pressure at 25-ppm Feedwater Concentration and 800 Degrees F. Curve *b*, as a Function of the Feedwaer Concentration at 1400 Pounds and 800 Degrees F.)

noted that even with a 1000-ppm feedwater only about 17 ppm are carried over. Curve *a*, Figure 5, refers to a 25-ppm feedwater and shows the salt concentration of the superheated steam as a function of the pressure over a very large range. At 1000 pounds per square inch, for instance, less than 2 ppm are carried over, but for any type of boiler the quantity of salts carried over is not as important as whether they are of the kind that will stick to the turbine blades.[1]

Considerable improvements have also been made in the Benson boiler control. While a change of heating or of the volume of feedwater of drum-type boilers affects primarily only the quantity of steam produced, the steam temperature will be what may be according to the disposition and amount of the surface of the superheater. Of course, various means such as by-passing

[1] See " Cause and Prevention of Turbine-Blade Deposits," by Frederick C. Straub, Trans. A.S.M.E., vol. 57, 1935, pp. 447-454.

superheating elements are employed for the purpose of maintaining constant temperature. This requirement of maintaining constant temperature has become important with the advent of modern operating steam temperatures because a small increase above the designed temperature would become dangerous. In the case of the Benson boiler the difficulty of proportioning the superheater does not obtain. To express the difference in operation between the two types of boilers in homely language: With the drum type, one feeds fuel directly in response to pressure, and indirectly to load demand, and then feeds water in response to a level gage. With the Benson boiler, the process is somewhat reversed, one feeds water in response to load demand, and then fuel in response to a temperature indication. This comparison must not be taken too literally; obviously, both fuel and water should be simultaneously adjusted in response to load demand with a correcting impulse in response to temperature.

As will be explained later, there is a certain interval of time between the moment combustion is changed, as for example by changing the heat value of the fuel, and the moment the effect on the steam temperature becomes noticeable. A change in the firing of a Benson boiler can have its full effect on the steam temperature only after the feedwater has gone through the entire boiler, which takes one and one-half to several minutes, depending on the load. An additional delay is caused by the heat inertia of the mass of metal of the superheater. It is obvious that under such conditions boiler operation is difficult, since temperature-controlled regulation will necessarily lag and result in overregulation. This difficulty has been remedied by the use of an auxiliary heating surface, as shown in Figure 6, which consists of a

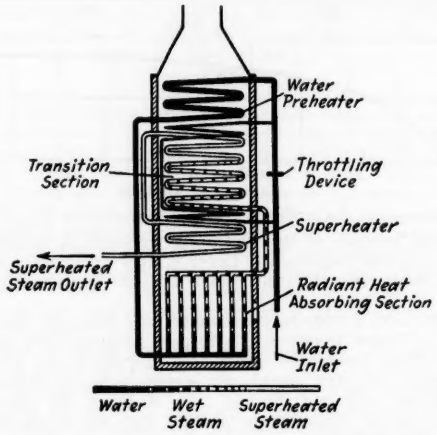


FIGURE 6.—BENSON BOILER WITH AUXILIARY HEATING SURFACE FOR CONTROL.

thin tube of $^{10}/_{16}$ millimeter (0.39/0.63 inch) diameter, connected in parallel with the main heating surface or part of it. The auxiliary heating surface amounts to only a very small fraction (about $^{1}/_{1000}$) of the total heating surface. Water at high velocity is forced through the auxiliary tube, in which

it is not evaporated, but only heated. The water passing through the auxiliary tube being proportional to the total volume of water, its temperature rise is therefore a direct measure of the heating and temperature of the boiler. Since it takes only about ten seconds to pass through the auxiliary heating tube, changes in the firing become manifest before they can have any effect on the steam temperature. Therefore, if the heat supply is regulated in such a way that the heating of the auxiliary tube remains constant, then also the steam temperature of the boiler will be held constant. As shown in Figure 6, a throttling device is built into the feedwater pipe line between the connections to and from the auxiliary heating tube, so that the desired water velocities will obtain. The auxiliary heating tube is now furnished with all Benson boilers and has operated satisfactorily in all installations thus equipped.

The regulation described in the foregoing applies only to corrections of undesired changes of firing or feedwater volume, and is, of course, merely a corrective supplement to the normal load-controlled regulation of feedwater, fuel supply, and air in their proper proportion. If fuel, air, and water supply are adjusted simultaneously, the desired increase or decrease in the steam production is obtained practically at the instant the increased or decreased fuel supply becomes effective in the combustion chamber, and delays in regulation are dependent solely upon the flexibility of firing.

Automatic control of a Benson boiler is not necessarily required, since half the boilers in operation are manually controlled. More than one system of automatic control is possible. One method of control has been developed and standardized by Siemens and Halske in which control impulses are obtained by Wheatstone bridges in combination with grid-controlled rectifier tubes. The resistance in one leg of the bridge changes in response to demand; that in another leg compensates by changing resistance in response to boiler operation.

Due to the economical conditions in Germany no new Benson boilers were installed between 1929 and 1933. In the years since 1933, however, the boiler industry experienced an exceptional upturn, so today there are in operation or under construction no fewer than 82 Benson boilers, which may be classified as follows:

43 boilers, average rating 176,000 pounds per hour each, for industrial plants with back-pressure or extraction-condensing operation
14 boilers, average rating 264,000 pounds per hour each, for public utility plants with condensing operation
6 boilers, average rating 26,000 pounds per hour each, for universities, testing purposes, etc., intermittent operation
19 boilers, average rating 73,000 pounds per hour each, for merchant marine ships.

These boilers were manufactured by the following firms under license from Siemens-Schuckert Werke: Rheinmetall-Borsig, Berlin-Tegel; Duerrwerke, Ratingen-Ost; Walther & Cie., Koeln-Dellbrueck; Vereinigte Kesselwerke, Düsseldorf; Krupp Germaniawerft, Kiel-Gaarden; Werft Blohm & Voss, Hamburg.

Table I shows how Benson boilers have shared in the total high-pressure-boiler orders placed in Germany, for pressures of 1150 to 2150 pounds, considering stationary boilers only.

Table 2 shows the installations in the German merchant marine. This excludes those boilers employed in naval service which cannot be referred to.

The materials employed for the tubing of Benson boilers are as shown in Table 3.

TABLE 1.—SUMMARY OF HIGH-PRESSURE STATIONARY BOILER ORDERS PLACED IN GERMANY FOR PRESSURES OF 1150 TO 2150 POUNDS.

	Number		Rating	
	No.	*Per cent*	*Tons per hr.*	*Per cent*
Stirling-type boiler	83	44.0	7515	48.7
Benson boiler	58	30.7	4850	31.5
Schmidt boiler	26	13.8	1537	10.0
Sulzer boiler	11	5.8	801	5.2
Sectional boiler	5	2.6	361	2.3
Loeffler boiler	5	2.6	255	1.7
La Mont boiler	1	0.5	90	0.6
Total	189	100.0	15,409	100.0

TABLE 2.—SUMMARY OF BENSON BOILERS INSTALLED ON GERMAN MERCHANT MARINE SHIPS.*

Name of ship	*Year of construction*	*Nautical miles*	*Number of boilers*	*Presure, lb. per sq. in.*	*Temp. F.*	*Rating each boiler, lb. per hr.*
Uckermark	1928	496,800	1	710	800	53,000
Potsdam	1935	288,600	4	1280	880	44,000/55,000
Pretoria	1936	132,000	2	1140	840	62,000/88,000
Windhuk	1936	106,000	2	1140	840	62,000/88,000

* The author has since been informed that the Hamburg-American line has under construction two 38,000-ton transatlantic liners to be propelled by the turbine-electric-drive system, each equipped with eight Benson boilers.

TABLE 3.—MATERIAL USED IN BENSON BOILER TUBING.

Steel	*St 45.29*	*TH 30*	*CS 65*
Analysis			
Carbon (C)	0.15	0.115	0.1
Sulphur (S)	0.004	0.008	.....
Phosphorus (P)	0.005	0.016	.....
Copper (Cu)	.....	.....	.....
Manganese (Mn)	0.4	0.47	0.4
Silicon (Si)	.....	0.11	1.2 to 1.5
Chromium (Cr)	.....	.....	2.5
Molybdenum (Mo)	.....	0.38	0.4
Physical Characteristics			
Ultimate strength, lb. per sq. in.	64,000 to 78,000	54,000 to 64,000	64,000 to 78,000
Elongation in per cent	17	20	20
Yield point at 932 deg. F., lb. per sq. in.	12,800	19,900	34,100
Creep limit at 932 deg. F., lb. per sq. in.	4,260	12,800	21,300
Creep limit at 1112 deg. F., lb. per sq. in.	0	2840	5300

DISCUSSIONS AND COMMENTS.

FACTORS INFLUENCING THE FAILURE OF NAVAL BOILER TUBES.

(SEE PAGE 1, FEBRUARY, 1939, JOURNAL.)

PAUL E. JORGENSEN, ASSISTANT MECHANICAL ENGINEER, NAVAL BOILER LABORATORY.—Lieutenant A. P. Calvert's paper presents very clearly the fundamental factors influencing the failure of Naval boiler tubes. The results of carefully carried out tests, as tabulated in the paper, answer a great many questions which are often left to guesswork.

Knowledge of the reasons for boiler tube failures is important from the standpoint of boiler design and operation. The method for determining temperatures at which tube failure apparently occurs has been an outstanding problem directly related with the casualty. However, it is considered that this factor is of secondary importance. The paramount consideration is the cause of the overheating. Tube ruptures are caused by overheating and are dependent upon design, construction or operation. The writer agrees that the statement, "a boiler tube probably failed through its having been heated to the plastic state," requires further amplification. A solution of the problems is one of physical metallurgy, as well as remedy of cause.

The author's analogy and method of microstructure comparison at the rupture of actual tube failures with those of the heat treated, water quenched specimens should prove very valuable. It is reasonable to assume from the correlated data that tube failure temperatures were in the range of 1500 degrees-1800 degrees F.; a region of oxidation and where little or no increase in creep strength is obtained. A mild steel tube will withstand pressures 2½ to 4½ times greater than those reported by the author at temperatures well within the upper critical temperature range prior

to rupturing. Although the temperatures may be sufficiently high to cause oxidation, it can be shown that the tube failures were charged to reduction in creep strength. Therefore, in actual service, a tube failure is chargeable in all probability to prolonged oxidation and reduction in creep strength. Overheated, gas bound tubes will produce a rupture with a knife-edge lip; however, it has been observed that all ruptures did not face the fire or hottest zone.

Sorbitic or martensitic structures normally observed in cases of tube failures tend to substantiate the correlations presented by the author in temperature of tube failure and microstructures of the failed tube.

Failures due to causes other than inadequate circulation may be corrected very easily, as ably brought out by the author.

NEWELL HAMILTON, METALLURGICAL ENGINEER, THE BABCOCK AND WILCOX TUBE COMPANY.—Lieutenant Calvert is to be congratulated upon a very able presentation and discussion of the factors surrounding the failures of marine boiler tubing. The literature on this subject is all too meager and this paper should prove to be of value in crystallizing the numerous and sometimes diverse opinions that are expressed.

In reviewing our own investigations of water tube boiler tube failures, both stationary and marine, we find that in the vast majority of cases failure may be attributed directly to overheating occasioned by one or more of the conditions outlined by the author. Almost invariably in the cases of generating tube failures positive metallurgical evidence of temperatures above the upper critical transformation of the steel are found in the edges of the fracture. In superheater tube failures, the evidence generally indicates lower temperatures at failure and the attack by dissociated steam with the formation of magnetite as mentioned by the author.

Section IV of the paper in which the influence of internal and external material defects due to manufacture is discussed is of particular interest to us. We feel that longitudinal scores and die marks and particularly internal laps and mandrel scratches are the most serious defects in seamless cold drawn boiler tubing. They are the result of low quality raw material, careless workmanship or improper tools, and recent years have seen vast improvements

in process control and tooling that have gone far toward eliminating these defects. In addition, the last few years have seen important developments in the hot working operations by which the tube blanks for cold drawing are manufactured.

The author's statements with reference to the bell and crush coupon test in specification 44T3e can scarcely be over emphasized. This test has had approximately one year of practical application and has proved to be of material aid in inspection and process control.

Being both makers and users of boiler tubing, we are continually alert to the developments of new processes of manufacture, and we have watched with considerable interest the recent developments in the application of electric resistance butt welding to the manufacture of boiler tubing. We have on several occasions investigated this process and its product and have carefully considered its merits and faults. As stated by the author, one factor in its favor is the ease of surface inspection of the skelp before the forming and welding operations. This should be balanced against the present day manufacturing methods used on cold drawn marine boiler tubes which involve inspection of the product in each step in manufacturing and consequent elimination of dangerous hidden defects in the finished tube. In this respect, it should be emphasized that the quality of raw materials in the form of tube billets necessary for the production of seamless cold drawn tubing is considerably higher than that required for flat rolled products. Furthermore, the final inspection of the cold drawn tubing is only a portion of the inspection procedure that is used on this product inasmuch as at each step in the production of the tube from the solid billet to the finished product the process demands a very thorough inspection control. We feel that the process inspection together with the actual deformation that occurs in the various section changes throughout the process is by far the most important element in regard to final tube quality.

The welding process used in the production of electric resistance butt welded tubing is capable of producing a joint of very high quality, but even under the most rigid control, defects can and do occur. The weld plane is in a radial position in the tube wall and is so thin that defects such as lack of fusion or partial oxidation in

the weld are microscopic in nature and may survive the most rigid type of inspection and remain a focal point for failure in service. In light of these facts we believe that for water tube boilers and particularly in the case of the exacting requirements of marine boilers continued development and perfection of the seamless process offers the best possibilities.

LIEUTENANT A. P. CALVERT, U. S. NAVY.—Reply to comments on "Factors Influencing the Failure of Naval Boiler Tubes."

The author agrees in the main with the remarks of Mr. Jorgensen that "tube ruptures are caused by overheating" and that "a mild steel tube will withstand pressures 2½ to 4½ times greater" than those used in the usual marine boiler. It would thus appear that temperature and pressure were the two major factors governing tube failures. Creep in low carbon tubes subjected to internal pressure, at temperatures within the critical range is not accepted as a cause of rupture by most high temperature authorities, yet in the cases discussed in the paper being commented on, creep probably played a more important role than did internal or external heat corrosion. Recent test work at the Naval Engineering Experiment Station has shown that boiler tubing stressed by internal pressure at temperatures up to 1800 degrees F., while moderately scaled, appear to exhibit the thick-lipped type rupture of a partially dry tube with only occasional evidence of intergranular corrosion.

Referring to the comments of Mr. Hamilton, the author recognizes the necessity for the improvement in the waterside surface finish of boiler tubing and feels that the use of the resistance butt welded method of fabrication might result in a better product in this respect. However, it is not felt that the use of welded tubes will solve the tube failure problem wherein temperatures above the upper critical, 1550 degrees F., are exhibited as determined by metallographic examination of the rupture.

ASSOCIATION NOTES.

ANNUAL BANQUET.

The Annual Banquet of the Society was held on the evening of April 13, 1939, at the Willard Hotel, Washington, D. C. One thousand seventy-two members and guests attended. The problem of seating such a number in the space available necessitated revision of seating arrangements, but was solved, with the maximum convenience and comfort possible under the circumstances. The fact that a very material number of desired reservations had to be declined on account of lack of room is a matter of much regret.

The occasion was an outstanding success from every standpoint. Speakers were:

Rear Admiral S. M. Robinson, U. S. Navy, President of the Society.

Mr. Lawrence Y. Spear, Vice President, Electric Boat Company.

Commander Frederick W. Pennoyer, Jr., U. S. Navy.

Dr. C. F. Kettering, Vice President, General Motors Corporation.

The Toastmaster was Commander Tully Shelley, U. S. Navy.

The speeches were excellent and have been the subject of numerous letters of congratulation.

A most enjoyable program of music was rendered by the orchestra of the U. S. Navy Band, together with vocalists, under the direction of Lieutenant Charles Benter, U. S. Navy.

JOURNALS FOR SALE.

Mr. Edwin F. Church, Jr., a member of the Society, whose address is 1282 East 24th St., Brooklyn, N. Y., desires to sell the following JOURNALS: Vols. 13, 1901, to Vol. 50, 1938, inclusive, complete except for No. 1, Vol. 14 and No. 3, Vol. 44, all with index, except for 1919. Volumes 13 to 21, inclusive are bound, leather back. All in excellent condition. The price is $75.00. Any one interested should communicate directly with Mr. Church.

MEMBERSHIP.

The following have joined the Society since the publication of the February, 1939, JOURNAL:

NAVAL.

Applegate, G. T., Ensign, U. S. Coast Guard.

Bailey, Vaughn, Commander, U. S. Navy.

Blaylock, Leroi B., Lieutenant, U. S. Navy.

Chapman, Joseph E., Lieut. Commander, U. S. Navy.

Corwin, Arie A., Commander, U. S. Navy, Retired, McNab, of Bridgeport, Inc. Mail address, 97 Inwood Road, Bridgeport, Conn.

Dodge, Harry B., Lieutenant, U. S. Navy.

Fletcher, William B., Jr., Lieut. Commander, U. S. Navy.

Gardner, Kinloch N., Lieutenant, U. S. Navy, Retired, 120 North Franklin St., Rocky Mount, N. C.

Hartman, Kenneth P., Lieutenant, U. S. Navy.

McEwen, Laurence C., Lieut. Commander, U. S. N. R., N. E. Dist. Engineer in Charge of Service and Installation, Cooper-Bessemer Corp., 1 Beachmont Ave., Gloucester, Mass.

Palmer, Lewis M., Lieutenant, U. S. Navy, Retired, Station L, Washington, D. C.

Pennoyer, Frederick W., Jr., Commander, U. S. Navy.

Schreiner, Max, Lieutenant, U. S. Navy.

Scruggs, Richard M., Lieut. Commander, U. S. Navy.

Stefanac, Joseph B., Lieutenant, U. S. Navy.

Stockstill, R. E., Lieutenant, U. S. Coast Guard.

Tedder, Fondville L., Lieutenant, U. S. Navy.

Thompson, E. C., Jr., Ensign, U. S. Coast Guard.

Van Kammen, I. J., Lieut. Commander, U. S. N. R., Hotel Roger Williams, 31st St. and Madison Ave., New York, N. Y.

Wellbrock, J. Howard, Commander, U. S. Navy.

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Allen, Scott E., President CO Two Fire Equipment Co., 560 Belmont Ave., Newark, N. J. Mail address, 63 Ridgewood Ave., Glen Ridge, N. J.

Batsel, M. C., Department Manager, Sound Engineering, R. C. A. Manufacturing Co., Camden, N. J.

Brunet, Meade, R. C. A. Manufacturing Co., 724 14th St., N. W., Washington, D. C.

Clement, Lewis, Vice President in charge of Research and Engineering, R. C. A. Manufacturing Co., Camden, N. J.

Cochran, S. W., Engineer in charge of Government Sound Section, R. C. A. Manufacturing Co., Camden, N. J. Mail address, 264 New Jersey Ave., Collingswood, N. J.

Cole, John R., Secretary-Treasurer, Pitometer Log Corporation, 237 Lafayette St., New York, N. Y.

Coleman, John B., Manager, Transmitter Engineering Division, R. C. A. Manufacturing Co., Camden, N. J. Mail address, 102 Avondale Ave., Haddonfield, N. J.

Connelly, L. A., Sales Engineer, R. C. A. Manufacturing Co., Camden, N. J.

Deakins, F. R., Vice President in charge of Engineering Apparatus, R. C. A. Manufacturing Co., Camden, N. J.

Diffin, F. G., Technical Engineer, Brush Berrileum Co., Cleveland, Ohio. Mail address, 19 Eastern Parkway, Baldwin, L. I., N. Y.

Gunther, Clarence A., Naval Radio Engineer, R. C. A. Manufacturing Co., Camden, N. J.

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